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Twenty-third Annual Report

of the

National Advisory Committee for Aeronautics

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1937

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

TWENTY-THIRD ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1937

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ADMINISTRATIVE REPORT
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UNITED STATES
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LETTER OF TRANSMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Twenty-third Annual Report of the Committee covering the fiscal year ended June 30, 1937.

Franklin D. Roosevelt.

The White House,
January 7, 1938.

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LETTER OF SUBMITTAL

National Advisory Committee for Aeronautics,
Washington, D. C., November 29, 1937.

Mr. President:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to submit herewith the Twenty-third Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1937.

During the past year the United States has maintained its position in the forefront of progressive nations in the technical development of aircraft for both military and commercial purposes. This has been due chiefly to sound organization and liberal support of scientific laboratory research in aeronautics in this country.

The War, Navy, and Commerce Departments, having equal representation on the Committee, cooperate in every way in its work, and each receives the results of the scientific investigations conducted. Thus the research needs of all branches of aviation are met without overlapping or duplication of effort. The Committee's activities, however, are limited to research. They do not include experimental engineering in the application of research results to the development of military, naval, or commercial aircraft.

The greatly increased interest of the major powers in fostering aeronautical research and their determined efforts to excel in this rapidly advancing engineering science constitute a scientific challenge to America's present leadership. It is the responsibility of the National Advisory Committee for Aeronautics to see to it that the United States will not become dependent upon any foreign nation for fundamental scientific data on which to base the design of American aircraft. To do this effectively it will be necessary that this Committee continue to have the liberal and far-sighted support of the President and of the Congress.

Respectfully submitted.

Joseph S. Ames, *Chairman.*

The President,
The White House, Washington, D. C.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

JOSEPH S. AMES, Ph. D., *Chairman*,
Baltimore, Md.

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Chief of Air Corps, War Department.

ORVILLE WRIGHT, Sc. D.,
Dayton, Ohio.

GEORGE W. LEWIS, *Director of Aeronautical Research*

JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer-in-Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

JOHN J. IDE, *Technical Assistant in Europe, Paris, France*

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS
AIRCRAFT STRUCTURES
AIRCRAFT ACCIDENTS
INVENTIONS AND DESIGNS

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

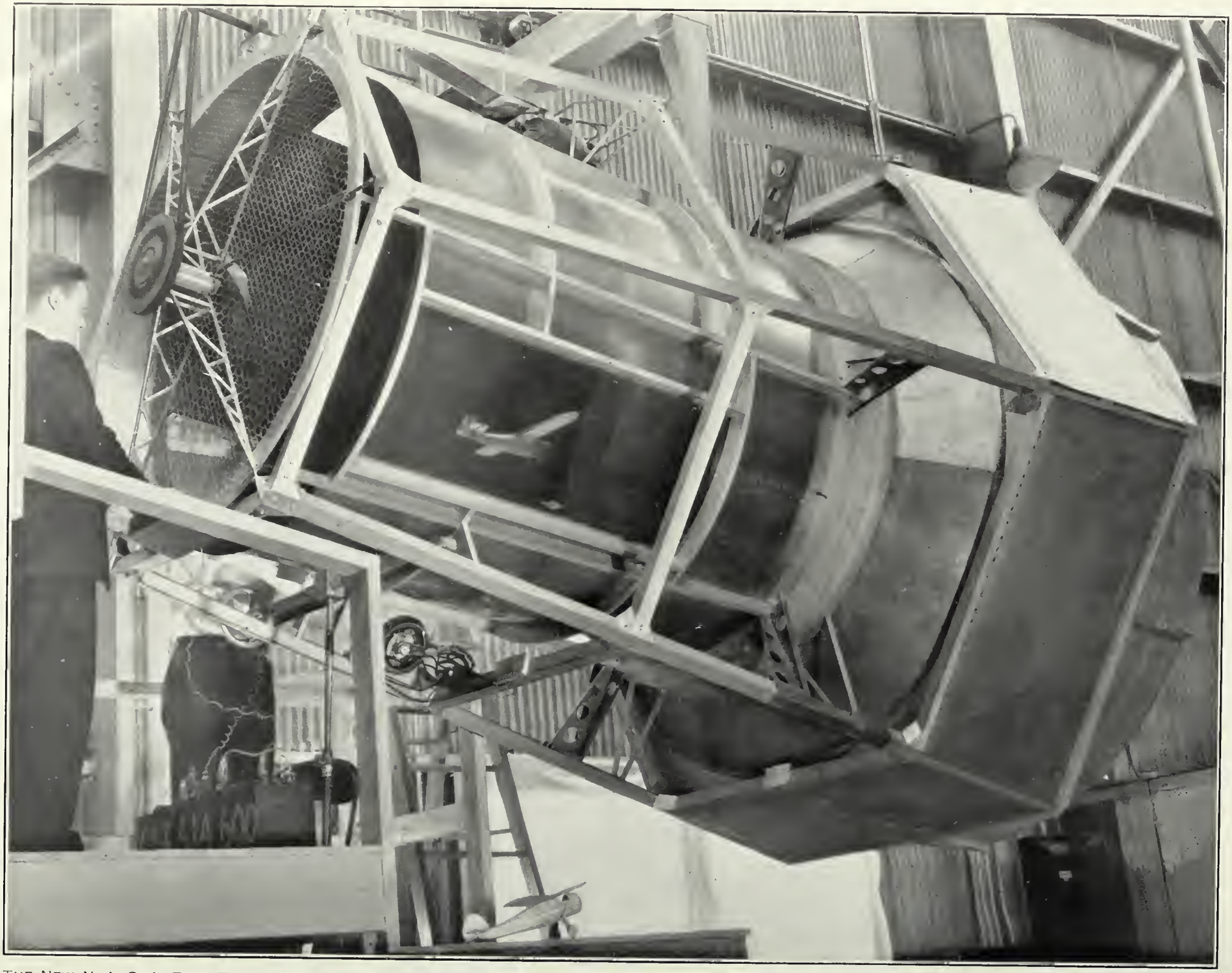
LANGLEY FIELD, VA.

Unified conduct, for all agencies, of scientific research on the fundamental problems of flight.

OFFICE OF AERONAUTICAL INTELLIGENCE

WASHINGTON, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics.



THE NEW N. A. C. A. FREE FLIGHT WIND TUNNEL IN WHICH INVESTIGATIONS OF AIRPLANE STABILITY AND CONTROL CHARACTERISTICS CAN BE MADE ON AN AIRPLANE MODEL IN FREE FLIGHT.

TWENTY-THIRD ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 10, 1937.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, section 151), which established the National Advisory Committee for Aeronautics, this Committee submits herewith its twenty-third annual report, covering the fiscal year 1937.

Responsibilities of this organization.—The prescribed functions of this organization are to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution," and to "direct and conduct research and experiment in aeronautics." In the discharge of its functions under the law the primary responsibilities of the National Advisory Committee for Aeronautics are: (1) To recognize in advance the trend of aeronautical development, civil and military; (2) to anticipate the research problems that will arise; and (3) to design and provide research equipment to meet the needs of this rapidly advancing engineering science, and then to conduct the necessary scientific investigations.

Created by law in 1915 as an independent Government establishment, the Committee, with the consistent and liberal support of the President and of the Congress, has gradually developed a large and well-equipped aeronautical research laboratory at Langley Field, Virginia. In this laboratory it has conducted fundamental scientific research in aeronautics with the sincere and indispensable cooperation and assistance of the War, Navy, and Commerce Departments. As a result, the scientific basis for aircraft design in the United States for both military and civil uses is not excelled in any other country. Long adherence to sound policy has won for the United States general recognition as a leader among the progressive nations in improving the performance, efficiency, and safety of aircraft.

The continued improvement in the performance of both military and commercial aircraft has confronted this Committee with a variety of problems that are pressing for immediate solution. Among examples of such problems may be mentioned the need for devising a method for studying the stalling characteristics of highly tapered wings; the determination of the necessary load factors and their variation with size and speed; the problem of reducing or eliminating if possible the formation of ice on wings, propellers, and control surfaces, and of providing effectively for the automatic removal of ice when it does form; problems involved in the design of wings, control surfaces, and flaps, as well as other devices to secure better control at low speeds incident to taking off and landing; problems of suppressing vibration and flutter, improving engine and propeller efficiency, capacity, and dependability, extending the range, enlarging the capacity, and at the same time constantly increasing the speed and safety of aircraft.

In addition to meeting urgent needs of the present, the Committee tries to look into the future and to anticipate some of the problems that may arise. For example, what are the maximum requirements for military and commercial aircraft going to be? Will speeds in excess of 400 miles per hour be required? How much will the size of commercial aircraft exceed 50 tons within the next few years? What are the problems that will require scientific analysis before such craft can be successfully designed and constructed? Will airships be further developed for naval use or for transoceanic transportation and, if so, what are fundamental problems this Committee should investigate?

The organization of research.—To analyze the present and probable research needs of aviation, civil and military, the N. A. C. A. has set up standing technical subcommittees on aerodynamics, power plants for aircraft, aircraft materials, and aircraft structures. The subcommittees are organized along lines similar to the main Committee and include specially qualified representatives of all the governmental agencies concerned with aeronautical development, as well as experts from private life. The members of the subcommittees, like the members of the main Committee, serve as such

without compensation. The subcommittees prepare and recommend research programs. The more fundamental problems are usually assigned for investigation at the Committee's laboratory at Langley Field, Virginia, primarily because of its special equipment for aeronautical research. Problems are also assigned to the National Bureau of Standards, so as to make the best use of available Government facilities and at the same time to avoid duplication in the field of aeronautical research. In the same manner problems are assigned and funds transferred to universities and technical schools. In this way aeronautical research is stimulated and coordinated.

Advances in the science of aeronautics have given rise to various trends, as the possibilities of aircraft increase. At the present time the trend of design of aircraft in all nations is definitely toward higher speeds and larger structures, with greater range and carrying capacity. This is true in both the military and commercial fields. Scientific and technical problems do not diminish but on the contrary increase in number and in difficulty with each advance in speed or size. It is the duty of this Committee to supply the fundamental data on which the design of new aircraft is based. If the Committee does not meet this responsibility adequately, the United States will quickly fall behind, because of the great emphasis now being placed on aeronautical research and development by other progressive nations.

Research facilities.—Up to 1932 the Committee had constructed at its laboratories at Langley Field, Virginia, known as the Langley Memorial Aeronautical Laboratory, special equipment such as the variable-density tunnel, the propeller-research tunnel, the full-scale tunnel, and the hydrodynamic laboratory—a seaplane towing basin. They were at the time of construction the only such pieces of equipment in the world. The possession of such equipment was one of the chief factors in enabling the United States to become the recognized leader in the technical development of aircraft. Since 1932 this research equipment has been reproduced by foreign countries and in some cases special research equipment for the study of problems in aeronautics has been developed and constructed abroad which is more modern than and superior to the equipment existing at Langley Field.

Since 1932 the importance of scientific research in aeronautics has been more generally appreciated by European nations and several of the larger powers have greatly augmented their research facilities and activities. The competition in the development of research equipment and facilities between the progressive nations is just as intense as the competition in the production of aircraft of superior performance. This condition has impressed the Committee with the advisability of providing additional facilities promptly as needed for the study of problems that are necessary to be solved, in order that American aircraft development, both military and commercial, will not fall behind.

In answering this scientific challenge the Committee has under construction at its laboratories at Langley Field a new wind tunnel having a diameter of 19 feet that can be operated under a pressure of three or more atmospheres at an air speed of more than 200 miles per hour. This tunnel will permit the investigation of the characteristics of large models of aircraft at much higher values of Reynolds Number than can be obtained in any of the Committee's existing wind tunnels. The Committee also has under construction a refrigerated wind tunnel for the investigation of the problems of ice formation on aircraft. This tunnel has throat dimensions of 7½ by 3 feet and will embody features and principles which, it is believed, will make it an effective instrument for the purpose intended.

The Committee during the past year developed an entirely new type of wind tunnel. The experience of the Committee in the operation of the free-spinning wind tunnel indicated the advantage of being able to reproduce and observe aircraft motion under controlled conditions in a wind tunnel. Methods of studying stability, control, and motion of an aircraft in previous types of wind tunnels, where the model is fixed on a balance, are long and laborious, and leave much to be desired in accuracy. Realizing the need for studying stability, control, and motion of a model of an aircraft when flying unrestrained, the Committee developed in the past year a new form of wind tunnel known as a "free-flight wind tunnel."

The first tunnel of this type constructed was 5 feet in diameter, and was so arranged that by tilting the tunnel its longitudinal axis could be set parallel to the glide path of the model under test. To do this the tunnel was suspended from above at a single point so that the axis of the wind tunnel could be varied through a wide range of angles, making this tunnel what might be called a "tilting wind tunnel."

The results obtained with this small tunnel were so encouraging that the Committee proceeded with the construction of a free-flight wind tunnel having a diameter of 20 feet.

With the establishment of commercial service across the Pacific Ocean by seaplane transports and the early prospect of such service across the Atlantic, operators and designers are focusing their attention on aircraft of larger sizes having improved efficiency and carrying more passengers and a heavier mail and express load. The design of the seaplane hull is a most important factor affecting the efficiency of transoceanic transports. Anticipating the need for extensive investigation of seaplane hull models in connection with the develop-

ment of larger seaplanes, the Committee during the past year modernized its hydrodynamic laboratory. The towing basin was lengthened from 2,000 feet to 2,900 feet. The towing carriage was enlarged and the operating speed increased so that investigations can now be made at speeds corresponding to the higher take-off and landing speeds of seaplanes.

The Committee's laboratories are on a portion of Langley Field assigned to this organization by the Secretary of War and are under the direct control of the Committee. The Committee believes that its laboratories, despite the recent great expenditures on research organizations abroad, are as yet unexcelled by those of any other single nation. In addition to the new research equipment under construction as noted above, the Committee's laboratories include: An 8-foot 500-mile-per-hour wind tunnel; a 60- by 30-foot full-scale wind tunnel; a 20-foot propeller-research tunnel; a 5-foot variable-density wind tunnel; a 7- by 10-foot wind tunnel; a 5-foot vertical wind tunnel; a 15-foot free-spinning wind tunnel; two high-velocity jet-type wind tunnels of 11- and 24-inch throat diameters, respectively; a hydrodynamic laboratory; an engine research laboratory; a flight research laboratory; and an instrument research laboratory.

Relation of Committee's work to national defense.—The relationship of the work of this organization to national defense has long been recognized and appreciated by the War and Navy Departments. The Army and Navy air organizations rely upon the N. A. C. A. to anticipate and to meet their research needs and thus to enable them to achieve and maintain leadership in the highly competitive field of military aircraft development. The safety and security of our country in time of war may depend upon a decision in the air. The course of a war will certainly be influenced in favor of that side which can gain supremacy in the air. Sound tactical organization, large numbers of aircraft, sufficient trained personnel, and ample productive capacity in the industry are not in themselves sufficient. The aircraft that engage the enemy in action must, if possible, be superior in performance. The hope of retaining our present superiority in technical development, in the face of the increasing emphasis being placed upon aeronautical research and development abroad, will depend largely upon the ability of this organization to solve promptly and effectively the fundamental problems attendant upon rapid progress in this branch of engineering science.

In this connection, the economic value of the work of this organization is worthy of reference. The procurement programs of the Army and Navy call for the expenditure of large sums to carry into effect the national defense policy approved by the Congress. Unless the aircraft procured are at least equal in performance to those possessed by other nations, their net value to the Army and Navy in time of war would be almost at the vanishing point. A national investment in inferior military aircraft would not only invite the risk of loss of the aircraft in time of war, but also the trained flying personnel. It would be as disappointing and disastrous as it usually is to try to win on the second-best hand in a poker game. Without up-to-date, reliable results of scientific laboratory research, our Army and Navy would not be able, even with the most sincere cooperation of the industry, to design and procure aircraft with any assurance that they would not be "second best" in time of war.

Commercial aviation.—The continued search for trends of development, and the effort to meet these trends by the provision of adequate research facilities and investigation of the right problems, also have a very important bearing upon the development of commercial aviation. Researches initiated primarily to meet military needs are in many cases broadened in scope to meet the needs of commercial aviation. Research problems peculiar to commercial aviation alone are also investigated. The Committee is materially assisted in this respect by suggestions from the Bureau of Air Commerce and from the air transport lines. Aircraft manufacturers also offer research suggestions and are alert to incorporate changes which the Committee's researches indicate will improve the safety or efficiency of aircraft. That the United States leads the world in the development and operation of commercial aircraft is due not alone to this healthy condition, but also in large measure to the national policy of air mail payment and to the indispensable assistance of the Bureau of Air Commerce in providing unexcelled air navigation facilities and otherwise helping in every practicable way to promote the safety and efficiency of air navigation. We cannot in this connection underestimate the importance of the meteorological service of the Weather Bureau in aid of safety, nor the numerous and valuable contributions to commercial aviation that have resulted from the experiments and developments on aircraft, engines, instruments, and accessories by the Army and Navy.

Our growing air transport business finds a healthy reflection in an aircraft production industry better equipped to respond to the needs of national defense in time of emergency. A healthy nucleus of an aircraft industry capable of rapid expansion in time of need is essential to our national defense. If it were not for the stimulation and support given the manufacturers by the growth of commercial air transportation in the United States, the aircraft industry would be so much weaker that, in view of disturbed world conditions at this time, there would be need for some form of artificial stimulation and development of productive ca-

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pacity. That we are not confronted with such a problem at this time is due partly to the fact that the results of the Committee's researches have made possible the development of commercial air transports in the United States superior to those of any other country. This has not only facilitated a rapid growth of commercial air transportation in this country, but has given to the American aircraft industry an advantage in world markets, evidenced by orders received from foreign countries for commercial airplanes of American manufacture.

The improved efficiency and safety of American air transports have permitted economies in operation, which in turn have resulted in material lessening of the cost of carrying air mail and of passenger fares.

Economic value of research.—No money estimate can be placed upon the economic value of greater national security through development of the means of producing superior military aircraft. Nor can a money estimate be placed upon the economic value of lives and property saved through improvements in the safety of aircraft. Nor can the educational advantages offered by air travel, the time saved, and the pleasure afforded to passengers be evaluated, nor the value to the nation of extending its national influence through world trade routes of the air. The researches of this Committee, however, do have a tremendous economic value that can be measured in dollars and cents. Improvements in aircraft that have resulted from the Committee's investigations and that have a definite economic value are numerous. Careful computations have been made of the economic value of a few of the more important contributions of this organization. These indicate that the annual savings in money made possible by the Committee's researches exceed the total appropriations for this organization since its establishment in 1915.

Summary.—With the rapid expansion of aviation in national defense, it is more than ever necessary that facilities be available for the prompt and adequate study of those fundamental problems in aeronautics that influence the speed, range, capacity, and control of aircraft.

The Committee believes that the future development of American aeronautics is largely dependent upon the support and effort given to the orderly and sustained prosecution of fundamental scientific research. It is the confident hope of the Committee that the United States will never be in a position where fundamental information necessary for the design of aircraft of maximum performance, efficiency, and safety will have to be imported from any foreign nation.

In commercial aviation the major problem is one of improving safety without penalizing those factors that are necessary to increase the speed, efficiency, operating range, and comfort of aircraft. When this Committee was established over twenty-two years ago there was but little appreciation of the value of aeronautics to national defense and practically no appreciation of the possibilities of aircraft in commerce.

Aviation has now become such an important factor in national defense, in the promotion of transportation in the United States, and in the extension of international commerce and good will that the organization and conduct of aeronautical research have attained the greatest significance and importance.

Foreign nations are making determined efforts to design and produce superior research facilities and to develop superior aircraft, both civil and military. The Committee in order fully to meet its responsibilities is endeavoring to modernize, improve, and augment its research facilities so as to maintain the present advantage of the United States.

To assure effective functioning on the urgent problems of the Army and Navy in time of war means for stabilizing the personnel of this organization must be found. From a study of the problem thus far it appears that enactment of legislation for this purpose may be necessary.

The Committee believes that the results achieved in the past and the problems to be faced justify a continuation of the liberal support of its work, and it further believes that in order to secure the best results there should be no change in its functions or in its status as an independent Government establishment.

PART I

REPORTS OF TECHNICAL COMMITTEES

In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These technical committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication.

In addition to its standing committees and subcommittees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

During the past year there has been a major change in the organization of the Committee's standing technical committees. The Committee on Aircraft Structures and Materials, which was one of the three principal technical committees, its Subcommittee on Structural Loads and Methods of Structural Analysis and the latter's Subcommittee on Research Program on Monocoque Design have been replaced by two coordinate committees, both reporting direct to the main Committee, namely, the Committee on Aircraft Materials and the Committee on Aircraft Structures. This change was made in recognition of the greatly increased importance of the problems of structural design in the field of aeronautics, and of the need for greater concentration of effort on these problems.

With this change in organization, the Committee has four principal technical committees—the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, the Committee on Aircraft Materials, and the Committee on Aircraft Structures. Under these committees there are six standing subcommittees. The membership of these technical committees and subcommittees is listed in Part II.

The Committees on Aerodynamics and Power Plants for Aircraft have direct control of the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the National Bureau of Standards. Most of the research under the supervision of the Committee on Aircraft Materials is conducted by the National Bureau of Standards. The greater part of the research under the cognizance of the Committee on Aircraft Structures is carried on by the National Bureau of Standards, but a number of structural investigations, especially those of a theoretical nature, are conducted at educational institutions and at the Committee's laboratory at Langley Field. The four technical committees recommend to the main Committee the investigations in their respective fields to be undertaken by educational institutions under contract with the National Advisory Committee for Aeronautics, and keep in touch with the progress of the work and the results obtained. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and aircraft structures undertaken by the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and other Government agencies are reported to these four committees.

REPORT OF COMMITTEE ON AERODYNAMICS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANDING SPEED AND SPEED RANGE

Flaps.—The use of wing flaps on high-performance airplanes is now almost universal. The research that has been conducted by the Committee during the past several years on the most promising forms of flaps has resulted in establishing their relative merits and has made possible the selection of the most satisfactory type for a given design. During the past year, attention has been directed mainly toward obtaining more specific design data for flap application.

In the variable-density wind tunnel, tests of ordinary and split flaps of 20-percent wing chord on the N. A. C. A. 23012 airfoil have been made with a large range of flap settings at a value of the effective Reynolds Number of about 8,000,000, for the purpose of providing designers with more reliable data as to the airfoil section characteristics for these combinations at large values of the Reynolds Number. While the results have not been completely analyzed, they corroborate, in general, the conclusions drawn from previous tests at lower values of the Reynolds Number.

The split flap is somewhat more favorable to speed range and landing speed than is the ordinary flap.

In the 7- by 10-foot wind tunnel a study of slotted flaps is under way in which tests of flaps of various shapes with slots of various forms are being conducted on an N. A. C. A. 23012 wing of 3-foot chord. With this installation, airfoil characteristics corresponding to a Reynolds Number of about 2,500,000 are being determined. The results to date indicate that with a properly designed slotted flap, unusually high maximum lift coefficients may be obtained. In addition, very low profile drag coefficients at high lift coefficients may be obtained with the flap deflected, which should result in improved take-off and climb characteristics. For controlling the glide-path angle, the slotted flap may be deflected beyond the angle for maximum lift without appreciably changing the lift coefficients. With this type of operation, the flap is similar to the glide-control flap previously described in Technical Note No. 552.

The results of the investigation in flight and in the full-scale wind tunnel, of a Zap flap mounted on a Fairchild 22 airplane, previously mentioned, have been published in Technical Note No. 596. Results of a similar investigation on the external-airfoil flap are presented in Technical Note No. 604.

Tests have also been made in the 7- by 10-foot wind tunnel for private companies and for the Bureau of Aeronautics of the Navy Department of the aerodynamic characteristics of several models equipped with flaps.

Maxwell slot.—The results of tests of another device for the improvement of speed range, the Maxwell leading-edge slot, mentioned in last year's report, have been published in Technical Note No. 598.

Measurement of minimum speed.—Opportunity was afforded during the year, in connection with the investigation of the maximum lift coefficient of a $2R_1 12$ wing on a Fairchild 22 airplane, to obtain a comparison between the flow conditions in flight and in the full-scale wind tunnel and thus study the effect of various test procedures and conditions on the measured minimum speed of an airplane. The main flight program covered the effect of wing loading and altitude on minimum speed. By extension of the program the effects of propeller position, throttle setting, wing-surface roughness, and the rate at which the angle of attack was increased were investigated. It was found that for a constant weight the minimum speed might vary by 5 percent, depending on the factors. The maximum lift coefficient obtained with one loading cannot be directly applied to the computation of the minimum speed with another loading, because of the variation of the lift coefficient with speed.

CONTROL AND CONTROLLABILITY

For a number of years the Committee has been engaged in a systematic wind-tunnel investigation of lateral control with special reference to the improvement of control at low air speeds and at high angles of attack. Many different ailerons and other lateral-control devices have been subjected to the same systematic investigation in the 7- by 10-foot wind tunnel and the devices that seemed most promising have been tested in flight. As has been stated in previous reports, the wind-tunnel and flight results were not always in agreement and indicated that, in determining actual control effectiveness from wind-tunnel results, it was necessary to include what had been previously considered secondary factors. A mathematical method of analysis was consequently developed to include those secondary factors and this method of analysis has been in use for about two years.

The experience gained has resulted in a revised basis of comparison of lateral-control devices and on this revised basis a critical résumé and analysis of the Committee's research to date on lateral control has been made and has been published in Technical Report No. 605. The analysis indicates that for normal-flight conditions, ordinary ailerons with the gap between the aileron and the wing sealed are the most generally satisfactory. An added advantage of these ailerons is that they appear to be practically free from icing hazards.

Slot-lip ailerons.—The complete results of the wind-tunnel and flight investigation of slot-slip ailerons have been published in Technical Report No. 602. It was stated in the last annual report that slot-lip ailerons installed on a Fairchild 22 airplane produced unsatisfactorily sluggish control, although such sluggishness was not detected by the pilots when these ailerons were installed on the W1–A airplane. An analysis made during the year has shown that the difference between the response of the two airplanes is explainable by the difference in their lateral-stability characteristics. Although some reduction in the drag of the slot-lip ailerons over that previously reported was obtained with a modified slot shape, the drag of this type of aileron is still considered excessive for modern high-performance airplanes.

The wind-tunnel investigation mentioned last year of the special form of slot-lip aileron, consisting of a plain aileron forming the trailing edge of an airfoil equipped with an external-airfoil flap, has been completed. The characteristics of these ailerons on an N. A. C. A. 23012 wing equipped with 20 and 30 percent chord full-span external-airfoil flaps of the same section were measured and are reported in Technical Report No. 603. These ailerons were found to be capable of developing large rolling moments but the hinge moments had cer-

tain undesirable characteristics and should receive further study.

Ailerons on tapered wings.—At the request of the Army Air Corps an investigation of the effectiveness of conventional ailerons on a tapered wing was made for direct comparison with a straight wing having ailerons of the same size. A 2:1 tapered wing with conventional flap-type aileron was mounted on a Fairchild 22 airplane and investigated in flight and in the full-scale wind tunnel. Conventional ailerons on this wing were found to be slightly more effective than ailerons of the same dimensions on a straight wing. The improvement was of the order of only 5 percent at low speed, and was so slight that it was not apparent to the pilots in the handling of the airplane. The results are being prepared for publication.

An investigation of ordinary sealed ailerons on two wings having medium and high taper ratios and partial-span split flaps has been described in Technical Report No. 611. The report presents aerodynamic information necessary for aileron design, including rolling, yawing, and hinge moments, as well as the aerodynamic characteristics of the wings.

Floating wing-tip ailerons.—Comparative tests were made in the full-scale wind tunnel and in flight to determine the relative effectiveness of floating-tip ailerons and conventional trailing-edge ailerons. The tests were made on a Fairchild 22 airplane equipped with a 2:1 tapered wing the wing tips of which could be removed and replaced by floating-tip ailerons. The floating-tip ailerons were made as large as seemed reasonable from considerations of structural weight. These ailerons were found to be approximately one-half as effective in producing rolling moment as conventional ailerons on the same wing. The floating-tip ailerons produced small favorable yawing moments while the trailing-edge ailerons produced appreciable unfavorable yawing moments.

Combinations of spoilers.—At the request of the Bureau of Aeronautics of the Navy Department, the lateral-control possibilities of combinations of spoilers arranged in tandem were investigated in the 7- by 10-foot wind tunnel. Since the time of response with such an arrangement was questionable, the investigation consisted primarily of measuring the response characteristics by means of a motion-picture study of the motion of a wing model restrained by springs but free to move when the control device was operated. The rolling moments produced by the control devices were measured with the same installation. It was found that while a combination of front and rear spoilers without lag was possible, no improvement in control was obtained over that with the rear spoiler or retractable aileron alone when the wing was equipped with a full-span flap.

Reduction of aileron control forces.—With the increase in size and speed of airplanes, increased interest has been shown in means of reducing the forces required to operate ailerons. On a large percentage of airplanes aerodynamic balances of the Frise or slotted types are used, with an accompanying loss in control effectiveness. In addition, such balances, with their projecting surfaces, are subject to icing difficulties.

The use of trailing-edge tabs in the conventional manner to balance the control forces of ailerons is accompanied by a sacrifice of some control effectiveness. A less conventional but apparently more successful method of applying tabs to ailerons is to use a very narrow-chord full-span tab to increase the up-floating angle of the ailerons by deflecting the tabs downward on both ailerons in conjunction with a proper differential movement of the ailerons. A study of aileron hinge moments as affected by differential linkages has been made and the results published in Technical Note No. 586. The value of a tab and differential linkage system has been investigated with a large wing in the 7- by 10-foot wind tunnel and on a Fairchild 22 airplane in flight. The ability of the arrangement to reduce the control forces to any desirable value was verified in both installations.

The flight investigation, in addition to verifying, in general, the principles involved in the theoretcal analysis, has indicated certain practical details requiring further study. The effect of the tabs on the aileron floating angle appears to be critically dependent on the tab shape. Tabs consisting of flat plates extending back of the aileron trailing edge were found to have very little effect on the aileron floating angle and consequently little effect on the control forces, whereas tabs inset within the aileron contour are satisfactory.

Wind-tunnel tests have shown that the effectiveness of a given aileron may be increased considerably by sealing the gap between the aileron leading edge and the wing to prevent leakage of air at this point. The effectiveness of the seal is greatest for narrow-chord ailerons, the increase being of the order of 50 percent when the aileron chord is about 10 percent of the chord. The increase in effectiveness may be utilized to improve the controllability or, if the controllability is satisfactory, to reduce the control forces by the substitution of a smaller sealed aileron for one having a gap at the hinge.

The actual application of this system of improving lateral control or reducing aileron stick forces depends on how much leakage occurs at the hinge in a normal aileron installation. In order to study this problem, measurements were made of the lateral control of the Fairchild 22 airplane, which has ailerons having a chord of 18 percent of the wing chord, with the original aileron installation and with a fabric seal

over the gap at the hinge. A 30-percent improvement in the control effectiveness was obtained. On the basis of these findings, sealed ailerons of half the chord of the original ailerons, or 9 percent of the wing chord, were installed on the airplane. These ailerons are about as effective as the original unsealed ailerons but require less than half the operating effort.

Two-control operation of an airplane.—Control of an airplane by means of two controls instead of the three normally used has appeared to offer promise of simplifying the operation of an airplane. Flights have been made with airplanes in which both aileron-elevator and elevator-rudder combinations were utilized for two-control operation, but considerable uncertainty remains as to which of these modes of operation is likely to prove the better and also whether either of them is capable of affording the controllability required for safety in flight.

In order to obtain additional information on the subject, an analytical study was made of two-control operation of a conventional airplane by the method of the theory of disturbed motion and is presented in Technical Report No. 579. Control maneuvers were computed for various combinations of rolling and yawing moments with an airplane for which the lateral-stability derivatives were varied. It was concluded that, while the most desirable control characteristics would depend somewhat on the lateral-stability characteristics and on the rate of application of the control device, the two-control operation of an airplane would be most generally satisfactory with controls which gave primarily a rolling moment with a slight amount of favorable yawing moment.

Flying qualities of large airplanes.—As was mentioned in the last annual report, a research is in progress to determine how much is known quantitatively regarding the actual stability, controllability, and maneuverability of large airplanes, and also what the procedure should be in any investigation to determine these characteristics in quantitatve form. During the past year a program of investigation in flight covering the measurement of all the quantities believed to be of importance with respect to flying qualities, has been formulated, the instrumentation developed, and the program successfully tried with a single-engine five-place high-wing cabin monoplane. Some modifications in the original program regarding the measurement of the general stability and the effectiveness of the rudder control were indicated to be desirable. The modified program and certain items referring to asymmetric power conditions that could not be investigated with a single-engine airplane are being studied with a twin-engine bombardment monoplane, and the measurements have been initiated on modern transport airplanes.

Flight with unsymmetrical power.—The problem of flight with only the propellers on one side operating was investigated as part of the investigation of the power-on characteristics of large multi-engine models in the full-scale tunnel.

Flight with zero yaw, accomplished by banking the airplane slightly to balance the side forces due to the propellers and rudder, was found preferable to balancing the side forces by yawing without banking, both as regards the maximum ceiling and the rudder deflection required. For unsymmetrical power conditions, the losses in performance, aside from the reduction of the thrust, are due to the drag of the inoperative propellers and the deflected rudder. The propeller drag is the major item unless the propeller is feathered or allowed to free-wheel.

MANEUVERABILITY

At the request of the Bureau of Aeronautics, Navy Department, the Committee is undertaking an investigation of the maneuverability of several Navy airplanes primarily for the purpose of determining the maximum angular accelerations in pitch and roll to which the machines may be subjected. The tests have been completed on two airplanes. The investigation includes measurements of the angular accelerations in rolling produced by abrupt use of the ailerons alone and also by combined use of the ailerons and other controls. Pitching accelerations are investigated in abrupt pull-ups from level flight and in recoveries from vertical dives. In all cases the angular accelerations are correlated with the linear accelerations of the center of gravity. In addition to the measurements of angular acceleration, information is being obtained on the pressure inside the wings during vertical dives and data are obtained to compare the loss of altitude in recoveries from dives with that predicted by means of charts developed as a result of previous investigations.

In connection with the study of the vertical-dive maneuver, the velocity-altitude relations for airplanes have been studied. Charts have been prepared (Technical Note No. 599) that present in a readily usable form the solution of the relation between time, velocity, and altitude for airplanes having various terminal velocities. The variation of density with altitude is taken into account on these charts.

STABILITY

A review of all available previous and contemporary work on stability, which was mentioned in the last annual report, has been completed and an extensive program outlined for systematic research in the various facilities available to the Committee. Work is now in progress upon several of the projects deemed to be the most urgent.

The investigation of new equipment for the study of stability is being continued. An experimental 5-foot free-flight wind tunnel has been developed to a point

of satisfactory operation. This tunnel can be used to study the free-flight behavior of models up to 22 inches in span. With a tunnel of this type it is possible to investigate inherent and controlled stability, motion in gusty air, stalling characteristics, the power of controls, and many other factors directly related to the actual free-flight behavior of the airplane. Even at the very low scale of tests possible in the present 5-foot tunnel, observation of model behavior has led to very interesting conclusions regarding the effects of such factors as the adverse yawing moments of ailerons, the effect of the position of the wing wake on the damping of longitudinal oscillations, the behavior of an aircraft when the tail is in the violent wake behind deflected split flaps, etc. The free-flight tunnel, of which the present 5-foot experimental version is the first and only one of the type, gives promise of greatly facilitating the entire study of aircraft motion.

Lateral stability.—Most existing work on stability deals with the inherent stability of the craft itself with the controls either fixed or free. Actually, the most usual condition of flight is that in which the aircraft is held to a definite course by either a human pilot or a compass-controlled automatic pilot. The pilot endeavors to bring the craft back to the course after a disturbance and in so doing alters the stability characteristics. A study of the stability of controlled motion along a definite course is now in progress and should show the effects of various ways of using the controls. It may also lead to a modification of present ideas regarding the importance and proper values of certain factors which affect the motion, since the present ideas are based on requirements for inherent stability.

In any study of stability with reference to a certain course, it is of great practical importance to know how the factors that govern the stability influence the magnitude and violence of the motion when an atmospheric disturbance is encountered. A mathematical study of motion in gusty air is being carried out and is approaching completion for the case of lateral motion.

A report on lateral stability in power-off flight has been published as Technical Report No. 589. This report parallels Technical Report No. 521, which deals with longitudinal stability. It includes discussions of the problem and of the individual factors involved. A number of charts are presented from which the lateral stability of a new design can be quickly and easily estimated.

One of the factors that most critically affects the lateral-stability characteristics is the rate of change of yawing moment with change in sideslip. There has been considerable uncertainty as to what allowance to make for the effect of the fuselage when this factor is estimated. During the past year, the Committee has undertaken a study of all readily available data on this factor with a view to developing suitable empirical relationships for its estimation. A technical note is being prepared giving the results of this investigation.

The investigation of the effect of tip shape and dihedral of rectangular monoplane wings on the lateral-stability characteristics, reported last year, has yielded basic information on the subject. For practical application to complete airplanes, however, the wing-fuselage interference would seem to be an important factor in determining the stability characteristics. Quantitative information on this effect will be obtained from an investigation that has been started in the 7- by 10-foot wind tunnel with fuselages of various cross sections and with tapered, swept-back, swept-forward, and rectangular wings.

Longitudinal stability.—Work is now in progress on a general study of longitudinal stability with power on. An attempt is being made to prepare charts similar to those in Technical Reports 521 and 589 to enable the designer to estimate quickly the effect of power on the stability.

The investigation of wing-fuselage interference in progress in the variable-density wind tunnel has been extended to include the study of the effects of adding tail surfaces to typical combinations. Conventional tail surfaces and horizontal tail surfaces with end plates are both being investigated with a view toward exploring the parameters of combination as affecting the aerodynamic interference, particularly as regards longitudinal stability. The effect on the moment of the tail surfaces entering the wing wake is noticeable but small, particularly when compared with the effect of the wing stall.

The analysis, reported last year, of the horizontal tail surface required for airplanes equipped with wing flaps, has been completed. A rational system for computing the horizontal tail area was evolved and has been presented in Technical Note No. 597.

A comprehensive investigation has been undertaken in the Committee's full-scale wind tunnel to determine the effect of propeller operation on the important characteristics of airplanes, such as the lift, stability, control, balance, etc. Full-scale data have been obtained for five airplanes having different geometrical arrangements, and a report presenting an analysis of these results is in preparation. These tests include measurements of the air-stream velocities and downwash angles in the region of the tail plane, and a study is being made to determine the variation of these quantities with the propeller thrust.

Stalling.—The problem of avoiding excessive danger from the stall has been a recurrent one. Most airplane manufacturers dealt with the problem rather satisfactorily several years ago, either empirically or through a

reasonably sound understanding of the phenomenon, gained as the result of research work both here and abroad.

In general, the solutions embodied the use of increased static longitudinal stability, thus providing a definite warning of the approaching stall through the backward movement, position, and forces on the control column, together with a gradually developing stall secured either by allowing the upper or lower wing of a biplane to stall first or by the use of monoplanes with little or no taper and with "poor" wing-fuselage junctures, which further tended to bring about a gradually developing stall, beginning at mid-span. These measures assured that the stalled condition would develop progressively after a reasonably definite warning; furthermore, lateral control was often maintained up to or beyond the stall (wing maximum lift), owing to the fact that the essentially effective parts of the wing system remained unstalled even after the angle of attack had exceeded that of maximum lift. Inasmuch as the pilot has little incentive to go beyond this point, such a solution was and still is considered satisfactory.

With such satisfactory solutions in common use, attention has for the past few years been diverted from the problem of minimizing stalling dangers. Recently however, modern design trends are bringing the problem back again in an acute form. These trends are toward higher wing loadings and landing speeds; the substitution of efficient high-speed sections having more sudden and hence less desirable stalling characteristics; the almost exclusive use of tapered-wing monoplanes; the use of increased taper; the low-wing position which contributes to reduced longitudinal stability with increasing lift; the use of "good" wing-fuselage junctures; and, finally, high-lift devices. The high-lift devices may further add to the dangers of tip stalling, add to balance and stability difficulties, and usually cause a vicious section stall corresponding to a sudden, large, and usually unsymmetrical loss of lift.

These trends have already gone so far that it now appears that many airplanes in common use cannot be considered reasonably safe, even for experienced pilots. The worst offenders may give no indication of an approaching stall which, when it occurs, is manifested by a vicious uncontrolled rolling dive, that results from a sudden loss of lift on the right or left wing and a simultaneous loss of lateral control.

During the year practical methods of avoiding these conditions in modern types of airplanes have been sought. The investigations have proceeded mainly on the theory that the vicious stall may best be avoided in monoplanes by causing the wing to stall progressively from the center toward the tips. Not only are the sudden loss of lift and violent roll thus avoided, but lateral control is maintained through the first stages of the stall and the tendency toward an upwash on the tail surfaces associated with the loss of lift near the center of the wing may be used to bring about a marked increase in longitudinal stability as the stall is approached.

In the first investigation conducted in flight, sharp leading-edge strips extending out along the wing from either side of the fuselage were employed to bring about the desired symmetrical center-stalling characteristic. Wind-tunnel experiments with airfoils having sharp leading-edge sections over a small portion near their midspan had indicated how the flight investigation should proceed. The flight investigations for the power-off condition showed that an airplane having vicious stalling characteristics could be improved as expected by thus bringing about a gradually and symmetrically developing center stall. The extreme maximum lift coefficient was, of course, slightly reduced, but the practical gliding or approach speed was not increased; in fact, it was actually reduced. This phase of the flight investigation is, however, only preliminary in that the airplane tested had no flaps or other high-lift devices, whereas the problem is of most practical interest and is probably more difficult when high-lift devices are employed. The investigations are being extended.

The method employed to start center stalling may be objectionable on the grounds that the sharp leading edges will always tend to reduce the maximum lift. An investigation in the variable-density tunnel of methods of accomplishing the same result without loss of maximum lift led to the development of a new device known as the "stall-control flap." The flap tends to produce a well-rounded lift curve similar to that produced by the sharp leading edge but, together with a split flap or other conventional high-lift device, high maximum lift coefficients may be obtained. A special wing incorporating a stall-control flap has been constructed and installed on an F–22 airplane converted to a low-wing type. Flight tests are now being started on this airplane and from preliminary results it appears that, besides bringing about the desired center stall, several attendant advantages, such as favorable induced yawing moments from the ailerons, may be realized through its use.

SPINNING

The 15-foot free-spinning wind tunnel has been kept busy with routine testing of scale models of specific airplanes. The Matériel Division of the Army Air Corps, and the Bureau of Aeronautics of the Navy Department, are requiring spinning tests of models of new designs that are expected to be spun extensively in service. Four such models have been tested during the past year and three more are being prepared for testing in the immediate future. The work carried on

in this connection includes not only tests of the particular design, but also investigation of changes necessary to improve the spinning characteristics where such changes appear to be necessary.

The free-spinning tunnel is available for the testing of models for commercial concerns, and two such models have been tested during the year.

A certain amount of general information is being gleaned from the test results with specific designs. Conclusions stated in the last annual report regarding the importance of the tail unit in spinning have been confirmed and amplified during the past year. As a result of tests of a number of models of modern low-wing monoplanes, it now appears possible to draw certain conclusions about the effect of changes in mass distribution on such designs. In most cases the spinning characteristics of low-wing types have been improved, and in no case have they been impaired, by moving weight from the fuselage to the wings. This fact is of special significance in view of the present trend toward multi-engine airplanes with the engines in the wings.

During the past year a method has been developed for measuring, on free-spinning models, the hinge moment required to reverse completely the rudder during the spin. Such measurements have been made on three models. Indications are that the requirements of rapid recovery from the spin and reasonably low rudder moments are in certain cases very difficult to meet with a rudder that is also satisfactory in normal flight.

In addition to the spinning of models of specific airplanes, a systematic investigation is being carried out in the free-spinning tunnel to determine the effects of changes in wing arrangement, in tail arrangement and mass distribution. This investigation is about 20 percent completed. It is designed to reveal the relative importance of the various factors which affect spinning and to show which of these factors is most deserving of more detailed study. The results to date tend to confirm the conclusion that the tail arrangement is the most important single item. The effects of wing plan form and tip shape are, however, of considerably greater importance than has hitherto been thought to be the case. The effect of wing section appears to be relatively slight.

Tests of a model of the Fleet airplane on the spinning balance, reported last year, have been published as Technical Report No. 607. An investigation on the spinning balance of effect of wing plan form on the spinning characteristics has also been completed and the results published in Technical Note No. 612. The tests included a rectangular wing with square tips and with rounded tips and a tapered wing with rounded tips. An investigation in progress will show the effect of airfoil section on the spinning characteristics of monoplanes with rounded tips.

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An investigation on the spinning balance of the effect of stagger of rectangular biplane cellules has been completed and will be the subject of a report. The range of stagger investigated was from negative 25 percent stagger to positive 25 percent stagger. While no general conclusions can be drawn regarding the effect of stagger, the results can be used in studying the steady spinning characteristics of particular airplanes.

Tests for the purpose of making a direct comparison between the actual spinning behavior of a low-wing monoplane and the behavior of a model of the same airplane in the spinning tunnel have been started. Some difficulty and delay have been encountered in obtaining a suitable airplane for the tests. Two have been tried in flight. With one, the oscillating nature of the spin made measurements impossible. With the second airplane, the rudder forces built up to such a magnitude on the entry into the spin as to make it extremely uncertain that the pilot could supply the force necessary to assure that the airplane would recover from the prolonged spins required for the measurements. The mechanical advantage available to the pilot in operating the rudder of this airplane was increased and the forces that the pilot had to apply were reduced to the extent that it was possible to continue the tests.

TAKE-OFF

The results of the investigation of the rolling friction of airplane wheels, mentioned in last year's report, have been published in Technical Report No. 583.

In the calculated prediction of the take-off performance of airplanes, common practice has been either to neglect the transition period between the end of the ground run and the beginning of the steady climb or to take it into account by assuming a simple motion, since the actual motion is too complex for simple mathematical treatment. This lack of knowledge regarding the motion of the airplane in the transition introduces, of course, a degree of uncertainty into the results. As mentioned last year, an investigation of this phase of the take-off was undertaken in an effort to eliminate this uncertainty. The study is now completed and the results are being prepared for publication. It was found that the calculated value of the air-borne distance required in taking off over a 50-foot obstacle might be subject to an error of about 10 percent if the transition is neglected.

The investigation served also to emphasize the difficulties which are encountered in attempting to obtain representative comparisons directly from take-off tests and which arise from the fact that it is practically impossible for a pilot to conform exactly to a prescribed procedure throughout a series of complete take-offs, particularly if the air conditions are not absolutely steady. At present an attempt is being made to

develop a method whereby the true take-off capabilities of an airplane may be evaluated without consideration of the personal element or the air conditions. One solution that appears promising is to determine from individual tests the relation between ground run, distance, and speed, and the relation between angle of climb and speed, the latter to be measured at some altitude where smooth-air conditions prevail. These quantities should not be appreciably affected by piloting and when properly combined, together with a suitable allowance for the transition, should provide an accurate measure of the take-off performance of an airplane. An investigation has been made to determine the feasibility of this system and the results are being analyzed.

The characteristics of the propeller producing the thrust are an important influence on the take-off. Available propeller data have to a great extent been rendered inadequate because of the changes in design necessitated by higher engine power and airplane speeds, requiring larger propellers of higher pitch and with three or more blades. For the purpose of establishing the design factor for propellers in this category, an extensive investigation on full-scale propellers has recently been made in the propeller-research wind tunnel. The investigation is more completely covered in a later section of this report.

The above-mentioned investigation that was made in the variable-density wind tunnel of ordinary and split flaps of 20 percent of the wing chord on N. A. C. A. 23012 airfoils indicates that neither of these flaps can be considered a satisfactory high-lift device for use in take-off because of the high profile drag caused by these flaps at high values of the lift coefficient. In this respect the ordinary flap is inferior to the split flap. At any value of the lift coefficient where the flaps are useful, a lower value of the profile drag coefficient can be obtained with the split flap than with the ordinary flap.

The stall-control flap previously mentioned, especially when combined with a low-drag trailing-edge high-lift device, appears to offer improvements in the take-off characteristics of flying boats and airplanes equipped with three-wheel landing gears, because this flap permits high lift coefficients to be obtained with the airplane in a level attitude.

LANDING

Landing loads.—At the request of the Bureau of Air Commerce and the Army Air Corps, the Committee is undertaking the accumulation of statistical information on the loads sustained by the landing gear in landings. Investigations have been made with four airplanes and one autogiro. Measurements of the attitude and vertical velocities immediately prior to contact and simultaneous measurements of the linear accelerations of the center of gravity and the angular accelerations in pitch are made in order to correlate the magnitude and direction of the resultant ground reaction and the approximate distribution of force between the main and tail wheels with the motion and attitude of the airplane at contact. The investigation will be continued as more aircraft become available. A preliminary analysis is being made of the data obtained thus far.

Stable landing gears.—The tricycle landing gear has recently been receiving considerable attention because of its possibilities for greatly improving the stability and handling characteristics of the airplane on the ground and for increasing the ease with which landings may be made. A study of the various factors affecting the geometrical arrangement of the landing gear has been made.

With the use of tricycle landing gears, the shimmy of the castering nose wheel has presented a problem. The Committee has made an analytical investigation of the stability of castering wheels as a result of which information was obtained as to the cause of wheel shimmy and several means of overcoming it were suggested. The allowance of a certain amount of lateral freedom of the wheel on its axle was indicated as a remedy. Model tests, and full-scale tests with the W1–A airplane, verified the indications of the analytical investigation and have shown that the shimmy of the castering wheel may be overcome by allowing a relatively small amount of lateral freedom of the wheel. To center the wheel, damping of the sidewise motion should be provided, which in the investigation described was done by curving the axle slightly.

The accelerations in landing of an airplane with a tricycle landing gear have been studied to ascertain whether the passengers might experience relatively severe accelerations in an emergency landing. The study revealed that the predominant acceleration was due to braking forces applied to the main wheels and that the vertical acceleration due to nosing over on the nose wheel should not be serious from the standpoint of passenger comfort.

AIRFOILS

The work on airfoils carried on by the Committee during the past year has been confined mainly to the consolidation of the large amount of data obtained in recent years and to the extension of its usefulness by providing more diversified and accurate methods of its application to practical problems.

Section characteristics.—Airfoil data obtained in the variable-density wind tunnel since 1930 have been corrected by the empirical method mentioned last year, to give more accurate section characteristics than it has been possible to obtain previously from tests of

rectangular airfoils in the variable-density wind tunnel. These corrected data are to be presented in two reports. The first of these (Technical Report 610) presents the complete results obtained from the investigation of related forward-camber airfoils, of which the N. A. C. A. 23012 airfoil is representative. The second report, now in preparation, will contain the complete results for a large number of miscellaneous airfoils investigated since 1930 and will also include a table giving the improved section characteristics for the airfoils on which data are presented in Technical Report No. 460. These results are reasonably complete at one value of the Reynolds Number. Since airfoil data must be employed in practice at widely different values of the Reynolds Number, scale effect must also be taken into account.

The results of an investigation of airfoil scale effect which have been available only in condensed form as a confidential report have been published in full in Technical Report No. 586. These data give the most reliable basis available for the prediction of airfoil-section data at values of the Reynolds Number other than that at which the section data published in the reports mentioned in the preceding paragraph were obtained. However, uncertainties in the present knowledge must be admitted, and it appears that entirely satisfactory results must await future research at full scale in a nonturbulent air stream. The difficulty is the lack of knowledge about the transition from laminar to turbulent flow in the boundary layer of the airfoil.

Many of the effects of scale, turbulence, and surface condition are intimately connected with the transition from laminar to turbulent flow in the boundary layer. The importance of these effects may be realized from an analysis of the effects of transition on the drag of airfoil sections. If it is assumed that the boundary layer over the surface of an airfoil is entirely laminar, remarkably low drag coefficients are found for the higher values of Reynolds Number. The drag coefficient for a flat plate with laminar boundary layer is 0.0008 at a Reynolds Number of 10,000,000. If the boundary layer is assumed to be turbulent from the leading edge onward, the drag coefficient is more than seven times as large as the laminar value at the same value of Reynolds Number, actually amounting to 0.0057.

It is known, however, that it is not possible to have a laminar boundary layer over the entire airfoil surface. Calculations made by the method given in Technical Report No. 504 show that at zero lift on the N. A. C. A. 0012 airfoil section separation would be expected if the boundary layer were laminar at about 55 percent of the chord back of the leading edge, because of the adverse pressure gradient existing over the rearward portion of the airfoil. If transition occurs at this point, the drag will be intermediate between the values given for the completely laminar and the completely turbulent flows, but will still be markedly less than that for the completely turbulent layer.

Some experimental results, including data from recent tests in the 8-foot high-speed wind tunnel and some theoretical considerations as well, indicate that with very smooth wings in an air stream having zero turbulence the transition may tend to remain near the laminar separation point. If such is the case, savings of approximately 40 percent of the wing profile drag at a Reynolds Number of 10,000,000 are indicated, as compared with that predicted from a normal extrapolation of data from the variable-density wind tunnel.

In this connection some direct evidence on the nature of transition has been obtained from an investigation carried out in the nonturbulent N. A. C. A. smoke tunnel. Boundary-layer surveys were made throughout the transition region on a smooth flat plate having an adverse pressure gradient. The investigation showed that while the extent of the transition region decreased considerably with an increase in Reynolds Number, the point at which marked changes in the laminar boundary-layer flow first occurred was independent of the Reynolds Number throughout the range included in the investigation. The transition region was close to the position at which separation of the laminar boundary layer was to be expected unless premature transition was brought about by slight roughness near the leading edge of the plate. The tests were carried to a Reynolds Number of 150,000 based on the distance from the leading edge to the calculated point of separation. Visual observation of the flow over the plate indicates that similar conditions may exist over the range of Reynolds Number up to 500,000. A technical note is being prepared presenting the results of this investigation.

Wing characteristics.—The calculation of the characteristics of tapered wings from airfoil section data has been continued with several wings of varying aspect ratio and taper ratio. The basic section data and the data on scale effect, if applied by the method described in Technical Report No. 572, will enable the user to reduce the wind-tunnel data and to estimate the best wing for a given airplane. The calculated characteristics of 20 tapered wings will be compared with the experimental results for the same wings.

Measurement of profile drag in flight.—It has been feasible to investigate the profile drag of an airfoil section in flight by means of the pitot traverse method. This method has been used in an investigation of the comparison of air-flow conditions in flight and in the full-scale wind tunnel, the data obtained being evaluated to determine the profile drag from the momentum loss in the wake of an airfoil. The airfoil was an N–22

section and was first investigated with a smooth surface that was later modified by the addition of a thread having a diameter of 0.01 inch and located on the upper surface about 5 percent of the chord back of the leading edge. The results indicated that the addition of the small thread increased the profile drag of the smooth airfoil by about 18 percent. The addition of another small thread to the under surface of the airfoil at the same chordwise location further increased the profile drag, the total increase due to the two threads being about 32 percent.

EFFECT OF RIVETS AND OTHER SURFACE IRREGULARITIES ON WING DRAG

Past investigations in the full-scale and variable-density wind tunnels have shown that rivet heads and other surface irregularities increase the drag of wings appreciably. As aircraft have been made otherwise more efficient, the importance of the increases in drag due to small surface irregularities has become more apparent and a need has arisen for more complete information on the magnitude of such drag increases.

An investigation has been made in the 8-foot high-speed wind tunnel to provide data on the effect on wing drag, over a comprehensive range, of rivet size, type, and arrangement, lap type and arrangement, and surface roughness. This investigation was made with a model of an N. A. C. A. 23012 airfoil of 5-foot chord at air speeds from 80 to 500 miles per hour at values of the Reynolds Number up to 18,500,000.

Rivets.—During the investigation tests were made of $\frac{3}{32}$- and $\frac{1}{16}$-inch brazier-head rivets, $\frac{3}{32}$-inch thin brazier-head rivets, and $\frac{3}{32}$-inch countersunk rivets in various chordwise and spanwise arrangements. The $\frac{3}{32}$-inch brazier-head rivets in a typical arrangement increased the drag of the smooth airfoil 27 percent at 225 miles per hour. The drag increases due to the other protruding rivet heads were approximately proportional to the height of the heads, indicating that rivets with the thinnest practical heads should be used. The countersunk rivets increased the drag 6 percent under the same conditions. Increasing the spanwise pitch of the rivets had little effect unless it was made more than 2.5 percent of the wing chord. The investigation showed that more than 70 percent of the rivet drag was due to the rivets on the forward 30 percent of the wing. About 66 percent of the rivet drag was due to the rivets on the upper surface of the airfoil.

Lapped joints.—A typical arrangement of conventional plain laps facing aft increased the drag over that for the smooth airfoil by 8 percent. Joggled laps increased the drag only half as much. Plain laps facing forward were found to be slightly inferior to plain laps facing aft, but if they were faired by rounding the edges of the sheets, the increase in drag was less than that with conventional laps facing aft. Rivets and laps employed together increased the drag only slightly more than rivets alone.

Surface roughness.—The effect of five different degrees of surface roughness on airfoil drag was investigated. At 225 miles per hour the drag of the smooth airfoil was increased 44 percent by covering the surface with 0.0013-inch carborundum grains. Even the roughness due to spray painting increased the drag 14 percent at this speed. Sandpapering the painted surface with No. 400 sandpaper made the drag as low as that of the highly polished airfoil. The investigation showed that there is considerable scale effect on the drag due to roughness.

Effect on drag of wing due to manufacturing discrepancies.—In order to determine the effect on the drag of a wing due to manufacturing discrepancies, such as waves in the metal covering sheets and inaccuracies in the profile, tests were made on a model wing constructed to represent average present-day tolerances and workmanship. The drag of this "service wing" was 11 percent greater than that of the truer wind-tunnel model when both had the same arrangement of rivets and laps, and was 42 percent greater than the drag of the smooth-surface wind-tunnel model without rivets or laps. This excess in drag of 42 percent is equivalent to 273 extra horsepower on airplanes of the size and speed of those used on present air lines.

AERODYNAMIC INTERFERENCE

Wing-fuselage interference.—A report is now being prepared on the interference investigation recently completed in the full-scale wind tunnel with an Air Corps YO–31A observation monoplane. The airplane was first tested with the original gull wing and then with parasol wing arrangements in which the wing was placed at various heights above the fuselage. When the parasol tests were made the gull-wing roots were replaced by a straight center section. For the purpose of determining the interference effects the principal component parts of the airplane were tested separately in addition to the tests of the complete machine for each wing arrangement.

An investigation of the effects of triangular and elliptical cross-sectional fuselage shapes on the aerodynamic interference between wing and fuselage has been completed in the variable-density wind tunnel, together with tests of a special shape of juncture. During the course of the tests it was shown that ordinary critical combinations could be sometimes benefited, as regards the occurrence of the interference burble, by very smoothly finished surfaces at the wing junctures. In this respect one special shape of juncture showed a very powerful effect, its use resulting in the suppression of the premature interference burble entirely, with no increase in the minimum drag.

An investigation has also been made to obtain a comparison between a combination including the airfoil-type fuselage, and an efficient conventional wing-fuselage combination. Tail surfaces have been added to typical combinations in an investigation comprising an extension of the program of wing-fuselage interference. An interesting development of this phase thus far is the surprisingly low drag found possible for such a complete model combination.

FORCED VIBRATIONS AND AIR DAMPING OF A WING SYSTEM

A theoretical study has been made of the vibration response and air damping of a wing-aileron system in a uniform air stream to impressed alternating forces and moments. The mathematical treatment is a direct continuation of that presented in Technical Report No. 496 to analyze the flutter problem. The response characteristics of the vibrating wing-aileron system in a complete range of velocities and frequencies up to the critical flutter conditions can be determined in any specific case without extensive calculations. Thus not only are the critical flutter velocity and frequency readily determined, but also the vibration response and the air damping at intermediate conditions. The study thus presents a more complete picture of the phenomenon of flutter than has previously been available in aerodynamic literature. In particular, it is shown that in the case of forced vibrations large responses may often be expected when flutter conditions are approached, even when actual flutter cannot occur. The results of this work are being prepared for publication.

PROPELLERS

Investigation of full-scale propellers.—The results of the investigation of six full-scale propellers in conjunction with a standard nacelle unit equipped with six different N. A. C. A. cowlings have been published in Technical Report No. 594. The investigation covered the complete range of flight conditions, including ground operation, take-off, climbing, and high-speed flight. The range of the advance-diameter ratio was extended far beyond that of earlier full-scale experiments, blade angles of 45° at 75 percent radius being included, which are equivalent to air speeds of more than 300 miles per hour for propellers of normal size and diameter.

An extensive investigation of full-scale propellers, which was planned last year and which will provide considerable data in addition to those just mentioned, has been proceeding for several months in the 20-foot propeller-research tunnel. A large number of tests of propellers of 10-foot diameter driven by a 600-horsepower engine have been made in conjunction with a cowled nacelle such as would house a radial air-cooled engine. A number of tests have been made also in conjunction with a nacelle for liquid-cooled engines.

The propellers on which this investigation is being made are of modern type, with the blade gradually fairing into the hub section, in contrast to the older type with airfoil sections carried in very close to the hub. Comparative tests indicate a small aerodynamic advantage for the latter type, but their use is precluded by the characteristics of existing engines.

In this investigation blade-angle settings up to 45° at 75-percent radius were also used and in several cases blade-angle settings up to 60°. A maximum efficiency was obtained under the conditions of this investigation at a setting of about 30° and there was little falling off even at 60°. This investigation gives further evidence that the old practice of designing propellers with a low basic pitch and then setting the blades at much higher angles should be modified for high-pitch propellers. It appears that high-pitch propellers should be designed to have a constant pitch when the blades are set at 20° to 30° at the 75-percent radius. This method will result in a smaller washout of pitch toward the hub at the higher blade-angle settings, which is of some advantage in obtaining the best thrust distribution for minimum energy loss.

During this investigation particular attention has been paid to the effect of tip speed on the efficiency in the take-off and climbing range of propeller operation. A small progressive loss in efficiency begins to appear when the tip speed reaches approximately 700 feet per second. There seems to be some variation with the airfoil section of the propeller, the Clark Y section holding its efficiency under these conditions to higher tip speeds than does the R. A. F. 6 section. Calculations from the data obtained show, however, that when applied to the controllable propeller the change in power coefficient is such that the propeller must be set at a lower blade angle than would be required if no tip-speed effect were present, with the result that the tip-speed effect is practically eliminated.

Analysis of the data obtained with propellers differing in airfoil sections, but otherwise similar, shows that the differences in characteristics are very small, as was expected. The analysis is not yet complete and other deductions may be possible after further examination.

A definite improvement is noted with a spinner on the propeller of a liquid-cooled engine, in contrast to radial-engine installations, where it was found that the use of a spinner over the hub had a negligible effect. An improvement of about 4 percent in the net efficiency of the liquid-cooled installation was caused by the spinner. In this connection a spinner just covering the hub and having the nacelle lines faired into it was found to be as good as a larger spinner.

A number of tests have been made in the negative torque (windmilling) region covering the conditions from zero thrust to propeller locked at blade-angle settings from 0° to 90°. The data from these tests will

provide information on the drag of idling and stopped propellers and on the braking effect of the propeller in the diving of military types of aircraft. It appears that the stopped propeller feathered to a blade-angle setting of 90° causes the least drag, but an idling propeller set at 50° and operating against normal engine friction has nearly as low a drag.

A series of five reports, each covering a section of this propeller investigation, is now being prepared. The many factors involved in a study of this scope require a division of the subject for the sake of clarity of presentation, as well as facility in use. Other reports may be required to present analyses of minor phases and data yet to be obtained.

Investigation of oppositely rotating tandem propellers.—The continual increase in the power ratings of airplane engines and the large propellers required, as well as the effect of torque reaction when large geared engines are used in small high-performance airplanes, have turned attention to the possibilities of oppositely rotating tandem propellers. The Army Air Corps requested an investigation of the problem, and Stanford University, which is a pioneer in propeller testing in the United States, agreed to make the investigation under contract with the Committee as a part of the Committee's program of cooperation with universities.

The investigation was made with model propellers of 3-foot diameter, and the results indicate that a 4-blade propeller is slightly inferior in performance to two 2-blade propellers of the same diameter and blade dimensions rotating in opposite directions. Both are, of course, inferior to normal 2-blade propellers. The spacing of the tandem propellers was varied from 8 to 30 percent of the propeller diameter, and practically no effect of spacing was noted except that the closer spacings produced more noise. At the lower blade-angle settings the rear propeller had to be set at a smaller angle than the front one in order to absorb the same power, but, as the blade-angle settings of the propeller were increased to give higher pitches, the rear propeller gradually required a setting higher than the front propeller. Increasing the propeller spacing of the tandem propellers when the blade-angle settings were in the low range also required an increase in the setting of the rear propeller. It is proposed to extend this investigation to compare a 6-blade propeller with two oppositely rotating 3-blade propellers.

Investigation of model propellers in yaw.—The characteristics of propellers whose axes are at an angle to the air stream are of considerable importance in the study of airplane stability with power on, and to some extent in the calculation of airplane performance. A series of tests of model propellers of 3-foot diameter in yaw has been made at Stanford University under contract with the Committee to provide data of this nature, and the results have been published in Technical Report No. 597.

Prediction of propeller performance from airfoil section data.—The analysis of airfoil section data as applied to the selection of sections for propeller blades has been continued during the past year. In addition methods for predicting the performance of propellers from the section data are being devised and further analysis made of the distribution of energy losses for conventional propellers. The characteristics of three propellers having different blade sections have been analytically determined from the section data obtained in the variable-density wind tunnel and the smaller high-speed wind tunnels, and three full-scale propellers of the same design will be tested in the 20-foot wind tunnel. The experimental data obtained should provide an excellent check on the method of predicting the performance analytically.

Propeller vibration.—The model method of determination of the dangerous vibration frequencies of propellers mentioned in the twenty-first anual report of the Committee has been verified and superseded by a method applicable directly to any propeller in question. The method consists in the use of a carbon-resistance strain gage attached to the propeller and a means for producing artificially forced vibrations of any mode, the propeller being electrically driven at full speed in a partial vacuum.

Propeller noise.—Experimental work on the sound emission from propellers has been continued, particularly with a view to obtaining greater absolute accuracy in the measurements. The intensity of the sound emitted from the propeller in various directions has been measured for the five lowest harmonics for the purpose of obtaining data for use as a basis for theoretical work. The measurements have been completed for the range of propeller tip speeds below the speed of sound in air and will be continued into the supersonic speed range.

A paper has been published (Technical Note No. 605) indicating the effect of blade thickness on propeller noise. The theoretical relations given in the paper permit calculation of sound intensity of long wave lengths from a propeller with symmetrical sections at zero blade angle. With the aid of experimental data, an empirical factor was introduced into the theoretical relations to make possible the calculations of higher harmonics of the rotation noise.

THEORETICAL AERODYNAMICS

Compressible flow.—The study of compressible flow about symmetrical Joukowsky profiles has been continued, and expressions have been developed for determination of the velocity and therefore the pressure distribution over the airfoils. In particular, lift and

pitching-moment formulas have been obtained for thin profiles at large angles of attack. It has been found that the expression for lift is analogous to that for incompressible flow, but that the expression for pitching moment, in addition to being analogous to that for incompressible flow, contains a term which amounts to a shift in the center of pressure toward the leading edge. In addition to developing the expressions for lift and pitching moment, the limiting value of the ratio of the air-stream velocity to the velocity of sound in an undisturbed stream has been calculated for several Joukowsky profiles, and the effect of angle of attack and thickness upon this ratio has been determined.

Pressure distribution on flapped airfoils.—A method has been devised for calculating the chordwise pressure distribution over airfoils with ordinary flaps. The distribution has been determined by altering the theoretical distribution and may be applied to airfoil sections having more than one flap. Technical Reports Nos. 360 and 563 show a disagreement between experimental and theoretical forces and pressure distribution. In the more recent analysis the empirical correction to the theory was determined through knowledge of the lift, pitching moment, and flap deflection. Work is continuing on this method of analysis to develop an expression for airfoils with split flaps.

WIND-TUNNEL CORRECTIONS

The interference of the wind-tunnel boundaries on the downwash behind an airfoil has been experimentally investigated, and the results have been compared with the available theoretical results for open-throat wind tunnels. This investigation has yielded results that are particularly valuable in correcting the downwash angle in the region of the tail plane. The experimental results show that the theoretical assumption of an infinite free jet at the test section of the wind tunnel may lead to erroneous conclusions if applied to the downwash in the region behind an airfoil where the tail surfaces would normally be located. The results of a theory based on the more accurate concept of an open-jet wind tunnel as a finite length of free jet provided with a closed exit passage gave good qualitative agreement with the experimental results. The results of this investigation have been presented in Technical Report No. 609.

The investigation to determine the scale effect on the maximum lift of an airfoil has been extended by additional tests in flight and in the full-scale wind tunnel. The investigation was made with a $2R_1 12$ airfoil mounted on a Fairchild 22 airplane, and the variations of Reynolds Number in flight were obtained chiefly by varying the wing loading of the airplane and by varying the altitude at which the tests were made. The maximum lift as obtained in flight and in the full-scale wind tunnel agreed within 2 percent, the results thus further substantiating the agreement obtained with sphere tests, which indicated a low percentage of turbulence in the full-scale wind tunnel.

The investigation of the factors leading to discrepancies between the power-on performance of an airplane as predicted from wind-tunnel data and as measured in flight is being continued. In order to avoid the difficulties usually experienced in obtaining precise measurements of climbing performance, the excess horsepower available for climb is being determined in level flight.

This determination is accomplished by the towing of parachutes of various sizes to absorb the excess horsepower at various speeds. The horsepower is computed from the tension in the towing line and the velocity of the airplane. This method avoids, in particular, the errors usually experienced in climb owing to variations in the wind velocity with altitude. A second airplane is being equipped to study quantitatively the effect on climbing performance of variations in the wind velocity with height by correlating the excess horsepower measured in level flight with the rates of climb actually experienced in several climb tests. The results will be checked by tests of the same airplanes in the full-scale wind tunnel under power-on conditions.

COMPRESSIBILITY EFFECTS DUE TO HIGH SPEED

Aerodynamic phenomena encountered at high speeds have heretofore been considered of importance mainly in relation to the adverse effects on propellers operating at high tip speeds. It has now been established that marked adverse effects due to compressibility may occur on other parts of airplanes when the forward speed of the airplane is approximately one-half the speed of sound. Investigations conducted in both the 24-inch and the 8-foot high-speed tunnels have shown that the compressibility burble results in a large energy loss. A large increase in drag may therefore occur when the flow about any part of the airplane produces a local velocity equal to the speed of sound. A bluff body and one having a high curvature produce high induced velocities, and therefore the critical speed of such bodies is low.

The results from an investigation in the 11-inch high-speed tunnel on the drag of circular and elliptical cylinders and prisms of triangular and square cross sections show that the critical velocities or, in other words, the forward speed at which compressibility effects become noticeable, may be as low as 0.4 the velocity of sound.

Similar results have been obtained in the 8-foot high-speed tunnel on a wing-nacelle combination. One-fifth-scale models of a family of radial-engine cowlings were tested on a nacelle with a wing of 2-foot chord.

Five of the cowling shapes had previously been tested in the propeller-research tunnel, and at the lower speed possible in the propeller-research tunnel these cowlings were considered satisfactory. One cowling shape was found to have a critical speed between 280 and 350 miles per hour, depending upon the attitude of the cowling and nacelle. When the compressibility burble, or shock wave, occurred at the critical speed the drag of the combination was increased from 50 to 200 percent, with only a slight increase in the tunnel speed.

During the investigation it had been found that if the pressure distribution over the cowling was known, the critical speed could be accurately predicted. Therefore, two cowlings were designed with the nose curvatures proportioned to reduce the peak negative pressure and obtain a uniform negative pressure distribution over the nose. By so changing the nose shape the critical speed of the cowling was increased to more than 500 miles per hour and approached the critical speed of the N. A. C. A. 23012 wing, which was used for the investigation. It was found that when the critical speed of the cowlings was increased other advantages were obtained. The cowling with the highest critical speed also had the lowest drag throughout the entire speed range, and the drag remained substantially constant over a larger range of angle of attack.

In order to determine at a large scale the possible variation in pitching moment with speed, four wings of 2-foot chord were tested in the 8-foot high-speed wind tunnel through a range of speeds up to that at which the compressibility burble was experienced. The four wings tested had the following N. A. C. A. sections: 0012, 23012, 23012–64, and 4412. The N. A. C. A. 23012 and 23012–64 airfoils were chosen as sections of low pitching moment and the N. A. C. A. 4412 as a section of high pitching moment. All the sections tested showed an increase in pitching-moment coefficient with increased speed, the increase amounting to as much as 45 percent at 500 miles per hour. This change in pitching moment has little practical significance in the case of an airplane on which a wing section having low pitching moments is used, because the resulting absolute change in pitching moment at high speeds would be of little importance in the design of the wing or tail surfaces. In the case of an airplane with a wing section of high pitching moment the change may be very important in high-speed dives.

BOUNDARY-LAYER CONTROL

The investigation of boundary-layer control has been continued in the propeller-research tunnel, and tests have been completed on a tapered wing of N. A. C. A. 8318 section with upper-surface suction slots to control the boundary layer. Tapering the slot was found to be very effective in producing an even distribution of control over the span, and the suction power required was intermediate between the low power required for a thick wing and the high power required for a thin wing. Measurements of boundary-layer thickness were made both with and without the control in operation.

ICE PREVENTION

In view of the fact that several accidents during the last year may be directly attributed to ice formation on the airplanes, a survey has been made of the ice-prevention investigations that have been conducted by the various Government and commercial organizations. A compilation of these data is being made so as to make available to all concerned information that may be valuable in preventing accidents due to ice formation.

In order to determine the effect of rubber de-icers on the aerodynamic characteristics of a wing, a model of a 5-tube de-icer was tested on an N. A. C. A. 23012 wing of 5-foot chord in the 8-foot high-speed tunnel. The results show that for both the inflated and deflated conditions the de-icers did not appreciably affect the lift or pitching moment for high-speed or cruising conditions, but with either two or three tubes of the de-icer inflated the drag of the wing was increased in the order of 80 percent. The conventional de-icer equipment deflated increased the drag of the wing 16 percent at 200 miles per hour. At air speeds greater than 200 miles per hour the de-icer lifted from the wing and in some cases breaks in the rubber were produced. In order to reduce the drag of the de-icer in the deflated condition a flush installation was made by the use of a metal attachment strip, which on the full-scale airplane would be 1/32-inch thick. With this installation the drag increment was reduced from 16 to 9 percent, but the same difficulty was experienced in the lifting of the de-icer from the wing at speeds greater than 200 miles per hour.

ROTATING-WING AIRCRAFT

The development of the direct-control type of autogiro has been delayed to some extent by the introduction of certain secondary difficulties connected with the provision of a satisfactory variation of control forces with air speed and with the elimination of vibration. A study of the effect on certain rotor characteristics of a periodic variation in blade-pitch angle has been made, and the results have been published in Technical Report No. 591. The predicted value of the flapping motion of the rotor blade was radically altered when the periodic pitch variation was inserted in the rotor analysis, and an appreciable influence of the periodic pitch on the rotor thrust coefficient was indicated. An analysis has been made of the factors involved and a method developed of predicting the periodic variation of the pitch angle. The results have been published in Technical Report No. 600.

An investigation has recently been conducted both in flight and in the full-scale wind tunnel on a direct-control autogiro to determine the lift, drag, control forces, flapping motion of the rotor blade, and periodic variation in pitch angle. The tests in the full-scale wind tunnel were made on the complete autogiro, on the rotor alone, and on the machine without the rotor to determine the interference effects between various parts. The data obtained from these tests are being analyzed for use in the study of any desired variation of the location of the center of pressure on the rotor.

An investigation has been started in the propeller-research tunnel on a series of model autogiro rotors having airfoil sections of different thickness and different mean camber lines, and will include two rotors that differ only in plan form of the rotor blades. This work is an extension of an investigation previously made in which the effect of airfoil section and plan form on the lift-drag ratio of an autogiro rotor was studied.

The analysis of the results obtained during the autogiro jump take-off tests has been completed and published in Technical Note No. 582. The report covers a theoretical study of the jump take-off without forward speed and includes an experimental verification.

An analytical study of the rotor-blade oscillations in the plane of the rotor disk has been made, and the results have been published in Technical Note No. 581.

A study of the autogiro rotor-torque equation has been made, and a report is in preparation which will include a solution of the problem in chart form.

MISCELLANEOUS TESTS OF COMPLETE MODELS OF AIRPLANES

The improved aerodynamic efficiency of the modern airplane has made it increasingly important to make tests on a complete model of a projected airplane before it is constructed. Consequently a large number of complete models have been tested in the 7- by 10-foot, the 20-foot, and the full-scale wind tunnels. Most of these tests have been conducted at the request of the Army and Navy, but several models have been tested for manufacturers at their expense.

The models tested in the full-scale tunnel have been ½ and ¼ scale, and the tests have included considerable development work that could be conveniently carried out on these large-scale models at considerably less cost than would be involved in doing the same work on the actual airplane after it has been constructed. Although this development work has restricted to some extent the research programs in the tunnels, it is felt that the tests have resulted in a large saving of money to the Government. It might also be pointed out that the development work in the wind tunnel will save much of the time required to take an airplane through the experimental stages and place it in production.

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NATIONAL BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Wind-tunnel turbulence.—Within the last few years the equipment used in the study of wind-tunnel turbulence has been redesigned for use with an alternating-current power supply instead of storage batteries. A description of the new equipment and of its performance has been published in Technical Report No. 598.

As mentioned in last year's report, the investigation of turbulence has been extended to include the measurement of the scale or eddy size of the turbulence as well as the intensity. The most satisfactory method of introducing turbulence into the wind-tunnel stream was found to be by means of screens placed across the stream, the scale being controlled by the size of the screen and the intensity by the distance downstream from the screen. The measurements of scale and intensity have been made and the aerodynamic effect of these two factors has been determined. The results of this work have been published as Technical Report No. 581. The screens described in this report are now regarded as standard equipment in the Bureau's 4½-foot wind tunnel and are used to introduce turbulence of the desired scale and intensity within the limits obtainable.

Preparations are being made to continue the study of turbulence by measuring the distribution of energy in turbulent motion with the wave length of the turbulence. According to recent theories the spectral distribution of energy is a characteristic property of turbulence related to the intensity and scale.

Boundary layer near an elliptic cylinder.—During the past year boundary-layer investigations have been in progress with an elliptic cylinder of 12-inch major axis and 4-inch minor axis, placed with the major axis parallel to the wind. The laminar boundary layer formed about the cylinder was previously studied and the results were published as Technical Report No. 527.

The recent work has consisted of the measurement of velocity distributions in the boundary layer with the air speed in the tunnel high enough to produce transition from laminar to turbulent flow in the layer before separation occurred. Two cases were investigated: the first with the low turbulence normally prevailing in the wind tunnel and the second with the stream turbulence raised to about 4 percent by means of the 1-inch screen placed 18 inches ahead of the cylinder.

Marked differences were found between the types of transition occurring in the two cases. Transition with the low stream turbulence was the result of a laminar separation, and occurred within a very short length of the surface, about an inch ahead of the point of separa-

tion of the turbulent layer. Work with the higher stream turbulence gave no evidence of a laminar separation, but showed a gradual transition extending over about a third of the distance from the leading to the trailing edge of the cylinder (i. e., over about 4 inches). This latter type of transition was very difficult to detect by any single means and was found only by careful study of the velocity distributions in the layer. In order to throw more light on the transition phenomena at the higher stream turbulence measurements were made of the fluctuations in velocity throughout the layer at various points about the surface. These measurements also showed the gradual nature of the transition.

Studies of transition.—The two different types of transition found on the elliptic cylinder suggested an extension of the work to cover the general effects of turbulence and Reynolds Number on transition, the purpose of the extension being to learn under what conditions each type of transition exists and how the region of transition shifts with changes in Reynolds Number and changes in scale and intensity of the stream turbulence.

As was pointed out previously, the location of the transition region could be determined with the available equipment only by extensive measurements of the distribution of mean velocity or fluctuation of velocity across the boundary layer. In order to facilitate the investigation, a new device for quickly and easily detecting transition was sought. Previous work has shown that transition occurs in the neighborhood of the point where the intensity of skin friction is a minimum. This immediately suggested the use of some device, such as the Stanton surface tube developed in England, by which the surface friction may be measured. However, the adaptation of the surface tube was not considered feasible on the elliptic cylinder. Instead a sliding steel band 6 inches wide and 0.002 inch in thickness was fitted about the cylinder so that the heated element of a hot-wire anemometer, fixed at the center of the band, could be moved around the contour of the ellipse at a small fixed distance from the surface.

While an actual measurement of the velocity by this means is not readily possible, the wire can be used to detect where the speed is a minimum as the band is slipped around the surface. In the tests already made a platinum wire 0.016 millimeter in diameter and 13 millimeters long was mounted 0.21 millimeter from the surface of the band. The device has proved quite satisfactory and shows sufficient promise to justify further development. It may be possible to use a device of this sort for locating transition on an airplane wing in flight.

Investigation of boundary layer by diffusion of heat.—The method of thermal diffusion described in Technical Report No. 524 has been applied to the study of velocity fluctuations in a thick turbulent boundary layer formed on the surface of a flat plate 10 feet wide and 24 feet long. The procedure consists of measuring with a thermocouple the spread of the heated wake downstream from a fine but long heated wire placed transverse to the flow in the boundary layer. The spread of the wake is caused by the components of turbulent motion normal to the mean direction of flow, and the purpose of the work is to compute the magnitude of the components from the measured spread. By this means the magnitude of the velocity fluctuations normal to the surface has been determined. In a similar manner it is planned to determine the magnitude of the component parallel to the surface. By the usual hot-wire equipment the component in the direction of the mean flow will be measured so that finally a comparison between all three components of the fluctuations will be possible.

AERONAUTIC-INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

Reports on aircraft instruments.—A report on the pressure drop in tubing used to connect aircraft instruments to vacuum pumps and pitot-static tubes has been published as Technical Note No. 593, and a report on electrical thermometers is being published as Technical Report No. 606.

An experimental investigation of the performance characteristics of venturi tubes used in aircraft for operating air-driven gyroscopic instruments has been completed and a report prepared.

Progress has been made on reports on the effect of vibration on service aircraft instruments and on gyroscopic instruments for aircraft.

Tests and test methods.—It was originally planned to measure humidity in the aerograph test apparatus by the dew-point method. A simpler method has been developed in which advantage is taken of the fact that completely saturated salt solutions have a characteristic vapor pressure so that a particular salt solution produces a practically constant relative humidity when placed in a closed chamber. Corrections can be applied for the relatively small variation of the relative humidity with temperature.

Altitude mercurial barometers for field use should withstand shipment without breakage and should be designed so that the accumulation of gas above the mercury column is easily removable. Principally for these reasons it is advisable to fill the barometer tube in the

field. Experiments with the Barnes type, which meets these requirements, indicate that the procedure to be followed is too complicated. In cooperation with an instrument manufacturer, the common-type altitude barometer has been modified to make it possible for the tube to be filled in the field by following a relatively simple procedure. The barometer must be designed so that the end of the tube is always well covered with mercury while the barometer is tipped from the normal to the upside-down position. The usual capillary restriction in the end of the tube must be of such size that the passage of gas is not impeded by mercury sticking in the capillary.

Laboratory test methods have been developed, and data on the performance obtained, on fuel-air-ratio indicators of the thermal conductivity type. In these tests known mixtures of nitrogen and hydrogen and of nitrogen and carbon dioxide were passed through the instrument subject to various conditions, such as temperature, pressure, and voltage.

New instruments.—Instruments designed and constructed for the Bureau of Aeronautics include: a helium purity meter utilizing a porous plug of a type recently developed commercially; a superheat meter of the electrical-resistance type for a K airship; an experimental pitot-static tube for installation on the wing tip of monoplanes. Development of a fuel flowmeter of the orifice type is in progress.

SUBCOMMITTEE ON AIRSHIPS

The Subcommittee on Airships formulates and recommends programs of airship investigations to be undertaken at the Langley Memorial Aeronautical Laboratory and maintains close contact with the work in progress.

The Committee recently published as Technical Report No. 604 the results of the investigation conducted by the laboratory at the request of the Bureau of Aeronautics of the Navy to determine the pressure distribution at large angles of pitch on fins of different span-chord ratios on a large model of the airship *Akron*. This investigation was requested by the Bureau to provide information particularly desired by the Special Committee on Airships of the Science Advisory Board, of which Dr. W. F. Durand, of Stanford University, is chairman. Mention is made here of the publication of the technical reports of this committee, which cover certain phases of airship technical problems.

Models and apparatus are being prepared for the investigation in the Committee's 20-foot wind tunnel of boundary-layer control on airship forms. This investigation will include a form with blower in the nose, and also a form with propeller in the rear with control of the boundary layer by both suction and discharge jets.

At a meeting of the Subcommittee on Airships held in January 1937, plans were discussed for the extension of the investigation of the forces acting on an airship during ground handling, as published in Technical Report No. 566, to include a study of the effect of wind gradient and also of the effect of fin angle. Consideration was also given to the desirability of conducting an investigation at the Committee's laboratory on the loads on the tail surfaces of an airship in flight, and also an investigation of the forces on a large airship model with tail surfaces of the form used on the *Hindenburg*.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The Subcommittee on Meteorological Problems keeps in contact with the progress of investigations being conducted by the various agencies on problems relating to the atmospheric conditions which are of particular importance in connection with aircraft design and operation.

Atmospheric disturbances in relation to airplane accelerations.—Extensive measurements of gusts have been made by the Langley Memorial Aeronautical Laboratory by means of flights to altitudes of 19,000 feet with a large military-type airplane and flights with a small light airplane. From partial analysis of the data obtained, it appears that it may be possible to correlate the gust strength and gradient with the energy available for turbulence in the atmosphere. The new results do not invalidate the conclusions previously reached tentatively that, in stable atmospheric conditions, with large wind gradients, vertical gust velocities of the order of 30 feet per second are reached in a horizontal distance of about 100 feet, and that the gust gradient increases with decreasing gust intensity.

Surveys of clouds of cumulus type indicate, in general, stronger downward-acting than upward-acting gusts. On one occasion a downward gust of 53 feet per second, which reached maximum intensity in a distance of 53 feet, was experienced.

The development of a special acceleration-altitude recorder for installation at various Weather Bureau stations throughout the country is nearing completion. When available, these instruments will be used in conjunction with air-speed recorders to obtain data on the relation between gust intensity and altitude.

The accumulation and analysis of records of accelerations on transport airplanes in regular operation is being continued with the cooperation of a number of the air transport operators. The records obtained represent conditions encountered in operation over practically every part of the United States, in transpacific operation, and in operation over the Andes Mountains in South America. Records from flying boats in the transpacific service indicate effective gust velocities as great as 33 feet per second, which is substantially equal to the maximum recorded on flying boats in service

between Florida and the West Indies and South America and on land transports.

Investigation of wind gustiness.—The study of wind gustiness, including both atmospheric turbulence under ordinary conditions and the fluctuations of wind velocity during the passage of cold fronts, conducted by the Daniel Guggenheim Airship Institute at Akron, Ohio, in cooperation with the Weather Bureau and the Bureau of Aeronautics of the Navy, has been continued. Additional measurements are being made by means of instruments installed on the radio tower at Akron and on movable towers placed at various positions in relation to the radio tower and to each other, with supplementary records obtained by the use of balloons and theodolites.

Ice formation.—The problem of ice formation is receiving considerable attention at the Langley Memorial Aeronautical Laboratory, and a report has recently been issued to American manufacturers giving the results of a study of the prevention of ice formation on propellers. In this report information is given as to the conditions under which ice forms on propellers, and an investigation conducted by the Committee on the propeller de-icer developed under the sponsorship of the Bureau of Air Commerce in cooperation with the B. F. Goodrich Company and Transcontinental and Western Air, Incorporated, is described.

The problem of ice formation on wings and ailerons is also being studied, and a report is being prepared presenting all the information at present available. In addition, a program is being formulated for the study of the effect on the aerodynamic characteristics of a wing, of ice particles that adhere after the de-icer has acted. Data on the shape and location of such particles for use in the preparation of this program have been supplied through the cooperation of the Air Transport Association of America.

Electrical phenomena.—The question of the possible effect of electrical phenomena on airplanes has been brought to the Committee's attention and will be discussed at a meeting of the Subcommittee on Meteorological Problems to be held in the near future. Observations of pilots on the subject have been obtained from a number of sources, and the question will be thoroughly studied by the subcommittee.

SUBCOMMITTEE ON SEAPLANES

World-wide interest in seaplanes has grown at an accelerated rate and almost every month has brought word of the launching of new craft of greater size and speed. Designers are discussing with confidence the construction of flying boats of magnitudes that would have been considered impracticable a few years ago and are looking forward to the construction of even larger and faster flying boats within a relatively short time.

With the increases in size and range have come increased get-away speeds and heavier loads on the hulls. The power required for the take-off of such large flying boats is sometimes 100 percent greater than that ordinarily used in flight, and in such cases the designer is confronted with the necessity of choosing between the use of larger engines involving a serious increase in weight and the possibility of shortened engine life as a result of running at excessive power during take-off.

The cost of these large flying boats makes it essential that the form of hull selected shall be the best possible compromise between the requirements of low drag in flight and good performance on the water. Research in the N. A. C. A. tank has therefore been directed toward the improvement of the over-all performance of flying boats and seaplanes by the reduction of the resistance on the water and the general improvement of the form of the hull. In contrast to previous work, the aerodynamic improvement is being given consideration at the same time.

Improvements to N. A. C. A. tank.—In anticipation of the demand for tests of models of larger hulls at higher take-off speeds, the Committee is enlarging the N. A. C. A. tank and increasing the speed of the towing carriage. When the work now under way is completed the tank will have 2,880 feet of water at a depth of 12 feet, which is an increase of 900 feet. The extension has been specially constructed to permit the generation and propagation of waves for use in testing models in waves and the simulation of operation in rough water.

The increase in length has been matched by an increase in the speed of the towing carriage. It is expected that when the alterations are completed the carriage will have a maximum speed of about 80 miles per hour. The carriage will also be able to tow much larger models.

At lower speeds, with models of the same size, it will be possible to increase the amount of testing per day because the ratio of the distance that can be used in testing and obtaining readings to the distance required for stopping and starting the carriage will be considerably increased.

A two-story office building has been built at the southern end of the tank and the shop spaces have been extended 100 feet.

Effect of variation in dimensions and form of hull on take-off.—The result of incorporating longitudinal steps on the forebody of a V-bottom hull was determined by an investigation of a series of models in which the form and number of steps were systematically varied. In general, the longitudinal steps were found to decrease resistance at high speeds by reducing the area in contact with the water, but to increase resistance at low speeds where the bottom is wetted out to the chines. One longitudinal step on each side of the keel was

superior to two longitudinal steps, except at high speeds and very light loads. Spray strips fitted along the steps reduced both the resistance and spray if they were set at the proper angle. This investigation is described in Technical Note No. 574.

Various methods of artificial ventilation of the step were investigated on two typical hull forms, one having straight V sections and one having chine flare on both forebody and afterbody. In both cases the chines aft of the step were clear of the water at the hump speed and above. When the chines were clear the step was ventilated by air flowing in from the sides and the introduction of additional air through ducts or slots produced no further change in resistance or trim. In the case of the form with chine flare, natural ventilation was delayed at speeds below the hump speed and artificial ventilation through ducts aft of the step resulted in an appreciable reduction in resistance and trim. The results of this investigation have been published in Technical Note No. 594.

Tests of models of representative flying-boat hulls.—The hull of the U. S. Navy PB–1 flying boat, which was built by the Boeing Aircraft Company in 1925, had two transverse steps very close together and a long extension carrying the tail surfaces. The forebody was much like that of the NC hull, from which it was apparently derived. Comparisons of its water performance as obtained in the N. A. C. A. tank with that of the NC hull and the Sikorsky S–40 hull are presented in Technical Note No. 576.

A model of the hull of the British Singapore II–C flying boat was investigated in the N. A. C. A. tank in response to suggestion of the Director of Research, British Air Ministry. This investigation made it possible to determine the hydrodynamic characteristics of a typical British hull form over an extensive range of loadings and speeds. It was found that the Singapore hull had higher resistance at the hump speed and lower resistance at higher planing speeds than the American hull with which it was compared. The results of this investigation, together with a comparison with similar results obtained in the British R. A. E. tank with the same model, are presented in Technical Note No. 580.

A large model of the hull of the British Short Calcutta flying boat was made from lines supplied by the British manufacturers and investigated in the N. A. C. A. tank. The form is the immediate predecessor of the Singapore hull, and is representative of British flying-boat design in 1928. The results of these tests, together with calculated comparisons of its take-off performance with that of typical American forms, are published in Technical Note No. 590.

Trim-angle indicator.—The importance of holding a seaplane at the trim angles that would give least resistance during the process of take-off was described in Technical Note No. 486, issued in 1934. In that publication there is described and illustrated a trim indicator for showing the pilot of a seaplane the trim angle at which the craft is traveling. Several versions of this type of trim-angle indicator have since been constructed and tested in service. It has been found that if a pilot has a trim-angle indicator and the information obtained from tank tests of the hull as to the trim angles that give least resistance during the take-off, it is possible for him regularly to take off in much shorter time than he requires when no such instrument and data are available. The pilot of a heavily loaded amphibian operating in the tropics reported that he attributed the uniformly successful operation of his craft, especially the ease with which it took off in smooth water, to the use of a trim-angle indicator that had been supplied by the Committee. In another case the use of a trim-angle indicator by a test pilot is credited with so greatly improving the take-off characteristics that a seaplane which at first appeared very unsatisfactory gave very good performance.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ENGINE POWER

The recent demand of aircraft designers for engines of increased power output has been fulfilled by the supplying of radial air-cooled engines developing 1,500 horsepower during take-off. This large increase in power has been obtained by increasing the number of engine cylinders and by designing the engines to take the greatest possible advantage of the antidetonating quality of the improved fuels now available for aircraft engines. These large engines will be used in aircraft designed to transport greater loads at increased speeds over present airways. The several investigations of the Committee on the cooling of air-cooled engines have indicated that it will be possible to cool satisfactorily engines of even greater power.

Engine performance with high octane fuels.—The greater percentage of the recent increase in power of aircraft engines is due to the use of fuels having increased antidetonating quality. An investigation to determine the maximum engine performance with fuels having a range of octane numbers from 87 to somewhat greater than 100 has been in progress at the Committee's laboratory during the past year, under the cognizance of the Subcommittee on Aircraft Fuels and Lubricants, and will be described in the report of that subcommittee.

Valve overlap.—The power of aircraft engines may be increased by removing the exhaust gases from the cylinder clearance volume. An efficient method of removing the exhaust gas is to operate with a large valve overlap

and low boost pressure. At the request of the Bureau of Aeronautics of the Navy Department, the Committee is determining on a single-cylinder test engine the performance and optimum valve overlap to give efficient scavenging of a radial air-cooled fuel-injection engine operating at a maximum speed of 2,200 r. p. m.

The results indicate that satisfactory scavenging can be obtained with a valve overlap of 130°. From the tests on the single-cylinder engine it was found that as the boost pressure was increased the gain in power with the two-valve cylinder was slightly less than that obtained in previous tests with a cylinder having four valves. The results showed that an engine operating with valve overlap would develop 25 percent more power at the same cylinder temperature than an engine operating with normal valve timing. The tendency to detonate was reduced so that the engine with valve overlap, for the one fuel tested, showed an increase in brake mean effective pressure of 25 percent without detonation as compared with the normal valve timing.

The 2-stroke-cycle engine.—Increased power output can be obtained from a given engine displacement by operation on the 2-stroke cycle instead of on the 4-stroke cycle. The availability of improved fuels having increased antiknock values has renewed the interest in the 2-stroke-cycle spark-ignition fuel-injection engine. An investigation has been conducted to determine the optimum location of the fuel-injection valve and the best arrangement of fuel-valve orifices for injecting the fuel into the engine cylinder. Favorable results have been obtained in a limited series of tests, and the research program is being continued to obtain information on the operating characteristics of this type of engine as affected by speed, scavenging pressures, and induction and exhaust conditions. With fuel of 100 octane number, scavenging pressure of 3 pounds per square inch, and a speed of 1,650 r. p. m., the single-cylinder engine developed an indicated mean effective pressure of 166 pounds per square inch, the corresponding fuel consumption being 0.37 pound per horsepower-hour. A maximum indicated mean effective pressure of 193 pounds per square inch has been developed with a fuel consumption of 0.44 pound per horsepower-hour. A positive valve-operating mechanism for this engine is being developed that will permit the maximum engine speed to be increased from 1,800 to 2,500 r. p. m.

Air intercoolers.—An analysis has been made of data from laboratory tests for the purpose of selecting the most desirable intercooler for various operating conditions—the cooling, drag, pressure drop through cooler, and weight of core being considered. On the basis of this analysis, a program of tests for intercoolers has been prepared that includes both full-scale tests in a wind tunnel and tests of promising cores in the engine laboratory.

COMBUSTION RESEARCH

A study of combustion both in spark-ignition and in compression-ignition engines has been undertaken with the object of obtaining new knowledge concerning the combustion phenomena. The problem of detonation in internal-combustion engines is being attacked with the aid of high-speed schlieren photographs to indicate the temperature variations in the front and rear of the combustion zone following ignition.

Ignition lag in compression-ignition engines.—The investigation of the effect of air temperature and density on the auto-ignition and combustion of Diesel fuel with a constant-volume bomb has been extended. Very little reduction in ignition lag is possible for the particular fuel under test by the use of temperatures and pressures in excess of those attained in compression-ignition engines. The combustion process, however, is more satisfactory at densities corresponding to considerable boost. A concentration of combustion products several times greater than that corresponding to the residuals in a compression-ignition engine is capable of definitely increasing the ignition lag. Technical Report No. 580 has been published giving the results of this investigation.

Compression-ignition engine with air flow.—The investigation of the fuel-spray and flame formation occurring in a compression-ignition engine having air flow that was set up by a displacer on the piston crown has been described in Technical Report No. 588.

Detonation in engines.—With a schlieren set-up and a high-intensity electric spark as the light source, by means of which 10 photographs are taken at rates up to 2,000 pictures a second with an exposure interval for each picture of approximately one-millionth second, photographs have been obtained that show clearly the depth of the combustion zone and also the burning of the end gases in normal combustion. No evidence has been obtained of any sonic wave preceding the combustion front. Such waves were artificially produced in the chamber and, although their effect on the combustion front was visible, they did not cause the charge to detonate. Even with very severe detonation, the combustion reaches all, or nearly all, the way across the combustion chamber before the detonation occurs. The results of this investigation are being prepared for publication.

An apparatus has been constructed and is being used for preliminary tests of the detonation of gasoline-air mixtures. The combustible mixture is prepared in a reservoir heated to a temperature below the auto-ignition point but sufficiently high to vaporize all the fuel. A portion of this mixture is then admitted by means of a poppet-valve mechanism to an evacuated tubular bomb heated to a temperature such that auto-ignition of the charge will occur after a relatively long

time. If this mixture is spark-ignited at one end in such a way that the normal flame can traverse the tube within this lag period, no detonation occurs. On the other hand, when the spark is so applied to the mixture that the flame travels only a large portion of the tube length, then severe vibrations, presumably due to detonation, are set up in the optical pressure indicator attached to the tube at the end opposite the sparking end.

Analysis of engine cycle.—The calculated ideal engine cycle does not include consideration of the actual combustion process, so that the results depart considerably from those obtained from engine tests. In order to obtain better correlation between theoretical and experimental results, a study of the spark-ignition engine cycle was made and a thermodynamic cycle set up closely approximating the actual operating cycle. From a consideration of this cycle, equations for the cycle characteristics, such as indicated horsepower and fuel consumption, maximum cylinder pressure, and point at which the maximum cylinder pressure occurs in the cycle, were written as functions of three combustion parameters that specify the rate, the completeness, and the position in the cycle at which combustion occurs. The variation of the combustion parameters with engine operating conditions was obtained from indicator cards. The cycle characteristics calculated from the combustion parameters agree closely with those obtained in the engine tests.

Air flow in cylinders.—An investigation has been started to determine the effect of air flow on combustion in spark-ignition engines. The air flow is set up by shrouds placed on the inlet valves. Preliminary tests have shown that with an orderly swirl in the combustion chamber the entire combustion front is rotated, but that there is little apparent effect on the combustion velocity.

FUEL CONSUMPTION

Any reduction in the fuel consumption of engines used in long-range or transport aircraft can be utilized to increase the useful load or the range of the aircraft. Large savings in fuel have resulted from the use of mixture indicators by commercial operators. The improvement in cylinder cooling has progressed to such a point that aircraft engines are capable of operating at mixtures leaner than are accurately indicated by commercial mixture indicators. The use of fuels of high octane number has also resulted in an appreciable reduction in fuel consumption.

Mixture distribution.—The results obtained from an investigation of the distribution of fuel to each cylinder of a single-row radial air-cooled engine by chemically analyzing the exhaust gases have been published as Technical Note No. 583.

Fuel distribution.—The use of a fuel-injection system instead of the conventional carburetor requires that additional air flow be set up within the cylinder to assist in mixing the fuel and air. A study has been started to determine the effect of air movement on the distribution of the fuel spray during the suction and compression strokes. The apparatus consists of a glass cylinder clamped between the jacket and the cylinder head of an N. A. C. A. single-cylinder test engine. The piston side thrust is taken on the steel liner, and a dummy piston screwed in the main piston moves in the glass cylinder with very small clearance. The air flow is made visible by goose down introduced with the inlet air and is recorded by high-speed motion pictures taken at a rate of 2,400 frames per second. Tests have been completed with a pent-roof cylinder head in which the inlet valves were shrouded to give different degrees of air movement. With the shrouds arranged to give a tangential swirl, the photographs show that the tangential swirl persists throughout the compression stroke. With the shrouds arranged to direct the air parallel to the cylinder diameter, a decided vertical swirl is produced. With the shrouds radially arranged, a general indiscriminate air movement similar to that obtained without shrouds is obtained. The data are being prepared for publication.

Decreased fuel consumption.—A study of the fuel-consumption characteristics of modern air-cooled engine cylinders at various values of engine speed and torque has been completed. The determination of these characteristics was made on two single-cylinder air-cooled test engines having compression ratios of 5.6 and 6.9, respectively. The results showed that to secure best fuel economy an engine should be operated at high torque and at 65 percent of rated speed. Increasing the compression ratio from 5.6 to 6.9 decreased the fuel consumption but did not change the air-fuel ratio that produced maximum power or minimum fuel consumption. A report is being prepared giving the results of this investigation.

Mixture-ratio indicators.—With transport aircraft maximum range is obtained by operating the engines at the air-fuel ratio giving minimum specific fuel consumption. The Committee is investigating the more promising types of mixture-ratio indicators suitable for aircraft. The use of these instruments is limited, however, to air-fuel ratios from 15 to 9. Since aircraft engines under cruising conditions are already operating at air-fuel ratios of approximately 18, there is need for an improved instrument that will include the full-range of mixture ratios. An investigation has been started to determine possible methods of operating such an instrument.

Exhaust-gas analysis.—As most commercial instruments for indicating air-fuel ratio depend upon one or

more constituents of the exhaust gases, it is important in connection with the development of such an instrument to know the correlation of these constituents with air-fuel ratio. The most reliable method of determining this correlation is by chemical analysis of the exhaust gases. An investigation to determine the correlation for a number of engines and a range of engine-operating conditions has been completed, and the results are in process of publication as Technical Report No. 616.

ENGINE COWLINGS

The N. A. C. A. cowling.—The results of the comprehensive investigation carried out with full-scale models of the N. A. C. A. cowlings in the N. A. C. A. 20-foot wind tunnel have been published in Technical Reports Nos. 592, 593, and 594. The effect of cowlings on the cooling characteristics of a Pratt & Whitney Wasp S1H1–G engine is reported in Technical Report No. 596.

Nose-slot cowling.—The preliminary results obtained with the nose-slot cowling in the wind tunnel have been described in Technical Report No. 595. This cowling is characterized by the fact that the exit opening discharging the cooling air is not, as usual, located behind the engine but at the foremost extremity or nose of the cowling. This nose-slot cowling is inherently capable of producing two to three times the pressure head obtainable with the normal type of cowling, because the exit opening is located in a low-pressure field. Thus identical conditions of cooling can be obtained at correspondingly lower air speeds. In general, the efficiency is found to be high, owing to the fact that higher velocities may be used in the exit opening.

Investigation of the nose-slot cowling has been extended to include flight tests on the XBFC–1 airplane. A two-slot design with an adjustable nose section controllable from the cockpit has given very good results. This cowling compares very favorably with the original installation of the conventional N. A. C. A. cowling. Greater pressure is available for cooling on the ground, while the top speed of the airplane is increased 8 miles per hour. This investigation is being continued to improve the ground cooling further and to eliminate some conditions of local heating caused by the change in direction of the air flow. In the second design of the nose-slot cowling tightly fitting baffles were used. These baffles were much superior to the service-type baffles, lowering the temperature of the cylinder heads 40° and requiring the expenditure of only one-fifth the power.

The in-line air-cooled engine.—With increase in the power output of the air-cooled in-line engine the difficulties of obtaining satisfactory cooling and low drag have increased. The Committee is investigating the problems connected with the cowling and cooling of a 6-cylinder in-line air-cooled engine. In the in-line engine the opening available for the entrance of the cooling air is quite small, so that the air must enter at relatively high speed. The air must be turned through 90° in order to flow over the engine cylinders. Owing to the relatively high velocity, it was found that 30 percent of the available pressure was lost in turning the air before it entered the cylinder baffles. The energy required for cooling was therefore high compared to the energy required in the radial engine.

A new cowling has been constructed that will insure a smooth flow of air over the cowling. Enlarged openings and passages on the air-entrance side of the cylinders will be used to reduce the turning loss of the air. From the results obtained in the tests on this cowling a supplementary investigation will be planned.

ENGINE COOLING

Aircraft engines must be operated at approximately one-half the rated power and with lean mixtures to obtain maximum range. Any improvement made in the cooling of air-cooled engines can be utilized in operating the engine at higher power output during take-off and in cruising with leaner mixtures.

Fin dimensions.—An analysis has been made to determine the best proportions for metal fins for given rates of heat flow, consideration being given to the minimum pressure drop across the fins, the minimum power required for cooling, and the minimum weight of the fins.

This investigation has shown that: A considerable improvement in the heat transfer of conventional aluminum fins is possible by the use of correctly proportioned fins; correctly proportioned aluminum fins will transfer more than 2.25 times as much heat as steel fins for the same weight and pressure drop; the best fin proportions for maximum heat transfer for a given fin weight and pressure drop are also best for obtaining a high heat transfer for a given power expenditure in cooling.

As a result of the investigation of fin dimensions it was found that, for a given width of fin and velocity, there was an optimum spacing below which the heat transfer rapidly decreased. In order to determine the cause of this decrease, an investigation has been started in which the type of flow of air around large-scale model cylinders is determined by means of smoke-flow pictures. A hot-wire anemometer is also used to determine the change from laminar to turbulent flow. The effect of cylinder diameter, fin space, and fin width on the type of flow is being determined.

Heat-transfer coefficients.—The calculation of the heat flow from air-cooled finned surfaces depends upon the experimentally determined heat-transfer coefficients. An investigation to determine the surface heat-transfer

coefficients of closely spaced fins from wind-tunnel tests with and without baffles and with blower cooling has been described in Technical Note 602.

An investigation has been made to determine the heat-transfer coefficients of closely spaced aluminum-alloy fins having a width of 1.22 inches and copper fins having a width of 3 inches. The primary object of these tests was to determine whether the heat transfer as calculated from a theoretical equation checked the experimental values for finned surfaces constructed of metals having different thermal conductivities. The optimum fin spacing with wide fins was also investigated.

Cylinder baffles.—A study has been completed of the aerodynamics of cooling air-cooled engine cylinders with baffles. The air passage was recognized to be a venturi and was studied from this point of view. The use of a baffle approximating the best venturi possible under the conditions imposed by a radial air-cooled engine resulted in an improvement of 20 percent in cooling on a model cylinder. When the results of this study were applied in the baffling of a modern 2-row radial engine the cooling on the head was improved 28 percent.

Further work is in progress on the problem of improving the cooling by changing the cylinder contour. An attempt is being made to overcome some of the difficulties in constructing a good venturi in the conventional circular engine cylinder. Although the study is being made for convenience on a model simulating the barrel of the cylinder, the results are applicable to the head of the cylinder. Since 80 percent of the heat is dissipated through the head, and since contour changes are more easily made on the head than on the barrel, the results will be applied to the head of the cylinder.

Blower cooling.—The results of an investigation on a cylinder with fins 1.22 inches in width and with spacings varying from 0.022 to 0.21 inch have been published in Technical Report 587. The cylinders were enclosed in jackets and cooled with air supplied by a blower. The results showed that maximum cooling was obtained with a fin spacing of 13 fins per inch and that the heat-transfer coefficient was not sensitive to the fin spacing for values near the maximum, whether more or less. With 11 or 16 fins per inch the heat transfer was 95 percent of that obtained with a fin spacing of 13 fins per inch.

The results of the investigation to determine the effect of fin width, fin spacing, entrance and exit areas of the jacket around the cylinder, separator plates, and fillets on the pressure drop and power required to force air around finned cylinders at air speeds from 15 to 230 miles per hour have been prepared for publication and will be released as Technical Note 621. An analysis has been made of the losses occurring around the cylinder. As a supplement to this work, some miscellaneous tests are being made to determine the effect of certain special jacket and baffle designs on the heat transfer and pressure drop of finned cylinders.

Cylinder-temperature correction factors.—The results of an investigation to determine the effect of engine power, weight velocity of the cooling air, and atmospheric temperature on the cylinder temperatures of a Pratt & Whitney 1535 engine under flight conditions have been published in Technical Note 584.

The study of the factors for correcting cylinder temperatures of air-cooled engines to a standard atmospheric temperature has been extended to include the correction factors for various flight and test conditions, such as level flight, climb, take-off, airplane stationary on ground, and conditions of constant mass flow of cooling air and of constant velocity of cooling air. The correction factors range from approximately a change in cylinder temperature of 0.6° to 1.1° per degree change in atmospheric temperature, the value of the factor depending on the flight or test condition. A report covering this work is being prepared.

Heat transfer.—The study of the cooling of air-cooled engines has been continued. A report has been prepared and will be published as Technical Report 612, presenting an analysis in which equations for the rate of heat transfer from the engine gases to the cylinder and from the cylinder to the cooling air, as well as equations for the average head and barrel temperatures, as functions of the important engine and cooling variables, are obtained. Data obtained in tests of single-cylinder engines of cylinders from Pratt & Whitney 1535 and 1340–H engines for checking the analysis and for providing the empirical constants in the equations for these cylinders are presented in the report. An illustration of the application of the equations to the correlation of cooling data obtained in flight tests of a Grumman Scout (XSF–2) airplane is also given in the report.

An investigation of the effect of turbulence in the cooling air stream on the cooling of the Pratt & Whitney 1535 cylinder showed that in some cases the turbulence caused an increase of as much as 30 percent in the heat-transfer coefficient of the fins for the same pressure drop across the cylinder. These data are included in the report.

Further cooling tests have been made on a cylinder from a Wright 1820–G engine for obtaining the constants of the heat-transfer equations for this engine.

Radiators.—A study of radiator design has been undertaken. The entrance and exit conditions are being studied with a view to improving their aerodynamic performance. The study has revealed that 50 percent of

the power required to cool a radiator is lost in the exit of the air from the radiator tubes in the conventional honeycomb tube radiator. The results show that an important part of this loss can be avoided. Further, the diameter and length of tubes for the minimum power to cool is being determined. The results will give the optimum dimensions for several operating conditions and installations.

COMPRESSION-IGNITION ENGINES

The compression-ignition engine is of particular interest as a power plant for transport aircraft because of its inherently low fuel consumption. The criticism previously made of the compression-ignition engine was that it could not produce the necessary high power outputs for take-off and that the weight of the engine would be excessive because of the high maximum cylinder pressures. The results obtained by the Committee in tests of single-cylinder engines with the N. A. C. A. displacer-type combustion chamber showed that the boosted performance of this compression-ignition engine was equal to that obtained from the latest type of air-cooled engines operating with fuel of 100 octane number. Under take-off conditions the maximum cylinder pressures developed in conventional air-cooled engines have been found to equal those in the compression-ignition engine. The two types of engines should therefore weigh approximately the same.

Prechamber type of combustion chamber.—The results of the investigation of the prechamber type of combustion chamber for compression-ignition engines have been published in Technical Report 577.

Integral type of combustion chamber.—The investigation of engine performance at 2,500 r. p. m. with a displacer piston and a vertical-disk form of combustion chamber has been continued. In order to accommodate the increase in the engine rotative speed from 2,000 to 2,500 r. p. m. the air induction and exhaust systems were altered and development work conducted to determine the proper air-flow passages and the arrangement of fuel sprays in the combustion chamber. Test results showed that with existing fuel-injection equipment the injection period was too long, as evidenced by late burning and a smoky exhaust. Even without the correct rate of fuel injection an indicated mean effective pressure of 260 pounds per square inch was developed at 2,500 r. p. m. for a boost pressure of 10 pounds per square inch. The corresponding specific fuel consumption was 0.42 pound per indicated horsepower-hour.

Altitude performance.—An investigation of the performance of a compression-ignition engine under altitude conditions has been completed, and the results showed the Diesel engine to be under no handicap when compared with the carburetor engine. Tests were conducted at pressure altitudes up to 30,000 feet and at temperature and pressure conditions up to 14,000 feet. Boosted performance was also determined at constant inlet-air temperature from boost pressures of 0 to 10 pounds per square inch over a range of exhaust pressures corresponding to altitudes from 0 to 19,000 feet. The scope of the research was expanded to include the investigation of the effect of single variables of temperature and pressure of the inlet air and exhaust back pressure. A report presenting the results of the work is in process of publication.

Single-cylinder and multicylinder engines.—An air-cooled compression-ignition cylinder having a push-rod-valve mechanism suitable for use on a radial engine has been designed by the Committee and is being supplied by the Bureau of Aeronautics, Navy Department, for investigation. The cylinder has the displacer form of combustion chamber developed by the Committee and will be used to investigate its adaptation to air-cooled cylinders. Information will also be obtained on the factors of multicylinder compression-ignition engine performance and the problem of air-cooling a compression-ignition engine cylinder.

The 2-stroke-cycle engine.—The investigation of the 2-stroke-cycle compression-ignition engine has been continued, and tests have been made to determine the effect of the shape of the inlet ports on engine performance. A cylinder liner providing 62 inlet ports, each of $^{11}/_{32}$-inch diameter arranged in three staggered rows and drilled at an angle of 56° from the radial, has been tested for several length-diameter ratios of the ports. Best performance was obtained when the length-diameter ratio was 0.7 and was approximately equal to that with the eight large rectangular ports previously used. Work is in progress to determine the effect of varying the timing and duration of exhaust on engine performance.

Fuel-injection rates.—The results obtained from the investigation of the rates of discharge from a single-cylinder fuel-injection pump connected to two injection valves have been published in Technical Note 600.

The increase in rotative speeds of the compression-ignition engines has resulted in inferior performance of the fuel-injection equipment. Special apparatus has been constructed whereby accurate and convenient determination of injection rates has been made for a group of available fuel pumps, plungers, and cams in various combinations. The tests included variations of engine speed and quantity of fuel injected for the several injection-system combinations. Results indicated the unsuitability of any available injection equipment to give satisfactory introduction of the fuel charge into the cylinder at engine speeds in excess of 2,000 r. p. m. and the urgent need for further injection-system tests and development.

Fuel-injection pumps.—An improvement in the performance of several compression-ignition engines has resulted from changes in the rate of fuel injection. A knowledge of the rate of injection of the various fuel-injection systems has been obtained only after investigation of their characteristics. A unit type of injection system was investigated to obtain a direct control over the injection rate by variation in the cam outline. A cam-operated injection pump was closely coupled to the injection valve, and the effect of changes in orifice diameter, injection-tube length, throttle setting, pump speed, type of injection valve, and cam outline was studied.

The cam outline directly controlled the injection rate during the first five pump degrees of injection for a large orifice diameter and a differential-area valve. After this time interval, leakage at the pump affected the control. An open nozzle in combination with a ball-check valve reduced the initial rate of discharge to about half that of the differential-area valve. This rate increased with fuel quantity to a maximum at cut-off. With the differential-area valve, the rate of injection reached a maximum a few degrees after the beginning of injection and an increase in fuel quantity did not increase this rate. An increase in pump speed decreased the maximum rate and increased the period in degrees. Increase in injection-tube length had less effect on the open-nozzle valve. Secondary discharges were not obtained under any operating conditions with short injection tubes, but were obtained with increase in tube length under operating conditions in which a high initial pressure wave was obtained. The orifice diameter materially affected the injection rate, owing primarily to the high leakage rate at the injection pump. The maximum rate decreased with decrease in orifice diameter. With a suitable pressure seal at the pump and a relatively large orifice diameter in a differential area valve, the rate of discharge should be controllable by the cam outline for the unit-type injector.

Fuel and combustion accelerators.—The efficiency of the compression-ignition engine at increasing loads is reduced by late burning during the power stroke. Some evidence has been presented that the problem of eliminating the late burning may not be entirely the mechanical process of fuel and air mixing but one also of overcoming chemical retardants. The use of chemical combustion accelerators in the fuel has been suggested as a possible means of overcoming this handicap. A tetranitromethane Diesel oil dope has been obtained and tested in various percentages in the standard laboratory fuel. The small improvement in performance (2 to 3 percent) was considered economically undesirable. A sample of a second combustion accelerator has been ordered for test. A program is also under way to determine the relative merits of combinations of fuel oil and alcohol in various percentages, particularly with respect to more complete utilization of the air charge.

Fuel investigation.—The correlation of engine-performance data requires a knowledge of the heat of combustion of the fuel used. The determination of this factor and the distillation characteristics of the fuel make possible the recognition of changes in fuels due to aging or replacement. The heating values of five samples of Diesel fuel used by the Committee for engine testing have been determined. The values found vary from 19,790 B. t. u. to 19,930 B. t. u. per pound.

The smoky exhaust obtained with compression-ignition engines operating at air-fuel ratios richer than the theoretical (15 pounds of air to one pound of fuel) indicates that considerable fuel is wasted in unburned carbon. An investigation is being made to determine the amount of this carbon and its variation with air-fuel ratio. The method used is to determine the actual hydrogen-carbon ratio of the fuel from complete combustion tests and the apparent hydrogen-carbon ratio from exhaust-gas analysis, the difference in the two values being the carbon in the exhaust. The actual hydrogen-carbon ratio of five samples of Diesel fuel oil representative of the fuels used during the past two years by the Committee has been determined. The values found varied from 0.160 to 0.161.

INSTRUMENTS

Fuel flowmeter.—Flight testing of the electrical type of indicating fuel flowmeter which has been developed by the Committee has been conducted by the Materiel Division of the Army Air Corps. The fuel flowmeter is being altered to incorporate desirable changes indicated as a result of the flight tests.

High-speed camera.—The design of a high-speed motion-picture camera to photograph combustion at rates up to 40,000 frames per second has been completed, and construction of the camera has been started. The operating principle of the camera has been checked by means of a mock-up of the camera.

Fuel-injection pressure indicator.—A piezo-electric pick-up unit has been adapted to a fuel-injection valve to obtain instantaneous values of the fuel pressure at the discharge orifice. The pressures are shown on a cathode-ray tube. Photographic records are made of these instantaneous pressure traces. The rates of fuel discharge calculated from the pressure records show a very close agreement with the rates measured on the rate-of-discharge apparatus. This unit allows a rapid determination of rates of fuel discharge and of any cyclic variations in the discharge.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—A spherical explosion vessel with central ignition and auxiliary apparatus for obtaining simultaneous records of flame travel and pressure development has been constructed. The bomb consists of two flanged hemispheres, about 10 inches in diameter, clamped together on a short ring of glass which affords a view of the flame in a narrow, vertical center-section of the bomb.

The progress of the flame as it spreads from the central spark gap is photographed on a film which is carried on a drum rotating at a known speed on a vertical axis. The movement of the film under the lengthening image of the narrow flame section produces a time-displacement record of the flame front.

Six diaphragm pressure indicators, designed with a view to securing high accuracy throughout the pressure range of the explosion, are mounted on the bomb. Each indicator is set to close an electric contact the instant some predetermined pressure is reached in the bomb. When the contact is closed a neon lamp of high intensity is lighted, which photographs on the rotating film as a line beside the flame trace. In addition to the six lamps corresponding to the six indicators, there is a lamp which flashes 1,000 times a second under the control of a tuning fork and a lamp which burns continuously to provide a reference line for the measurement of flame displacements. The film thus contains all the information necessary for plotting time-displacement and time-pressure curves for the explosion.

Formulas have been developed for calculating from these curves (1) the "transformation velocity" or fundamental speed at which the flame front advances into and transforms the unburned charge; and (2) the "expansion ratio" or ratio of the volume of burned gas to the volume of the same mass of gas before explosion at constant pressure. Experiments will be conducted with this apparatus to investigate the separate effects of charge composition, temperature, and pressure on transformation velocity and expansion ratio.

Some experiments were made in which a cylindrical glass bomb was used with no pressure indicator to determine the effect of water vapor on the period of subnormal flame velocity just after the occurrence of the spark. In equivalent mixtures of carbon monoxide and oxygen saturated with moisture at atmospheric pressure this delay period is very short and high-film speeds must be used to detect it. Constant flame velocity is attained much more slowly when the moisture content is reduced below about one percent by volume. The cause of the delay is not known and it is hoped that new information concerning it will be obtained with the spherical bomb.

A brief mimeographed circular outlining the combustion experiments which have been conducted at the Bureau in engines, soap bubbles, and bombs, and containing a list of published reports on these experiments has been prepared for distribution to visitors and to others interested. A mimeographed bibliography containing 162 references on high-speed pressure indicators, classified according to type, is also available.

Investigation of piston cooling.—As the output of aircraft engines is raised the problem of heat dissipation from the piston head becomes increasingly serious. A program has been outlined for determining the heat flow in suitable test specimens under conditions similar to those encountered in service by aircraft-engine pistons. Preliminary static experiments showed greatly improved heat transfer for a hollow steel specimen with internal cooling over a solid aluminum specimen of approximately equal strength, size, and weight.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Engine performance with iso-octane fuels.—As mentioned in the report of the Langley Memorial Aeronautical Laboratory above, an investigation is being conducted at that laboratory to determine the maximum engine performance with fuels having octane numbers ranging from 87 to somewhat greater than 100. In this investigation the engine performance has been determined with the N. A. C. A. high-speed single-cylinder test engine having a cylinder bore of 5 inches and a stroke of 5.75 inches. The tests have been made at an engine speed of 2,500 r. p. m. and a coolant temperature of 250° F. The desired octane number of the fuel has been obtained by using commercial iso-octane blended with a gasoline having an octane number of 18. For octane numbers greater than 100, tetraethyl lead has been added to the iso-octane.

Tests have been completed with fuels of 87, 91, 95, and 100 octane number as determined by the C. F. R. method. In addition, tests are almost completed on the iso-octane with 1 cubic centimeter of tetraethyl lead. The limiting performance of these fuels has been determined at maximum power and at best fuel economy for both incipient and audible knock. The results show that as the inlet-air temperature is increased for any one compression ratio the effectiveness of the fuels of higher octane number appreciably decreases. Only at the lower inlet-air temperatures are the greatest increases in performance realized for the fuels of higher octane number. The tests have shown that the power of the engine does not vary as the inverse square root of the inlet-air temperature, but as an approximately lineal function.

Stability of aviation oils.—The investigation of the stability of aircraft-engine lubricating oil, conducted by the National Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy, has been extended to include laboratory tests of the stability of oils

in an apparatus in which the oil flows in a thin film down the walls of a heated cylinder and thus simulates engine conditions. The investigation of this method is not yet completed, but the data obtained thus far indicate a correlation between the results of these tests and the results of tests which have been made in a Pratt and Whitney Hornet engine.

An investigation of the stability of compounded oils has been initiated in cooperation with the Subcommittee on Aircraft Fuels and Lubricants, and the effect of a number of compounding materials on the stability of the base oil has been studied. The results of this investigation will serve as a basis for the choice of compounded oils to be used in connection with the study of wear and oiliness characteristics of aviation engine lubricating oils.

Oil acidity and bearing corrosion.—The investigation, conducted by the National Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy, of the effect of increase in oil acidity during service on the corrosion of master-rod bearings has been continued. Study of oils in the apparatus for forming acids in oils has indicated that this apparatus can be used to produce changes in the acidity of oils similar to changes which occur during service in aviation engines. It has been found desirable to construct additional apparatus for use in this investigation and this apparatus is being designed.

Aviation engine wear.—The investigation of the relative wear with different oils in actual aircraft engines, carried out at the National Bureau of Standards in cooperation with the Bureau of Aeronautics and certain petroleum organizations, has been continued throughout the fiscal year. The assembly of the operating equipment for engine control and absorption of power is essentially completed. Considerable precautions have been taken to insure reproducibility of operating conditions. Special fixtures for use with the precision instruments required for measuring the engine parts are under construction.

Wear and oiliness characteristics of aviation engine lubricating oils.—The investigation of the oiliness and wear characteristics of mineral and compounded lubricating oils, conducted by the National Bureau of Standards in cooperation with the Army Air Corps and the Bureau of Aeronautics, was continued throughout the fiscal year. An apparatus for determining the differences in piston-ring and cylinder-wall wear with various oils and compounding agents under conditions approximating those of actual engine operation has been completed, and preliminary tests are in progress. Construction of a second wear apparatus of different type has been begun. The design and construction of a machine for the study of oiliness as related to friction in master-rod bearings is under way.

REPORT OF COMMITTEE ON AIRCRAFT MATERIALS

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

Weathering of aircraft structural sheet metals—light alloys.—The series of atmospheric exposure tests of aluminum-alloy sheet materials was completed during the spring of 1937 after four years' duration at three test sites, typical of conditions prevailing at a tropical marine, a temperate marine, and an inland location. The results amply confirm the tentative conclusions announced in last year's report concerning the most corrosion-resistant types of alloys and satisfactory coating treatments for all alloys of this general kind. A report intended for publication summarizing the essentials of the test and the important facts established is in progress.

Preparations are approaching completion for a new series of tests. This series, which is on a somewhat smaller scale than the two previous ones, will be conducted at only one location, a marine one. Hampton Roads Naval Air Station is the site selected. Both aluminum and magnesium alloys are included in the program of tests scheduled, which are intended primarily for investigating the effects of riveting, welding, and contact between unlike metals, as well as the merits of newly developed protective surface treatments. The manufacturers of these materials are cooperating actively in the preparations, and this will insure that the industrial aspects of the problem will receive the careful consideration they deserve.

Corrosion-resistant steel.—The trend toward the use in aircraft of corrosion-resistant steel in thin sheet form has led to the inauguration of a similar program on this type of material. Deterioration of this material, if it occurs, takes place in a different manner from that of the light alloys, and the inspection and testing procedure must be correspondingly different. In both programs the effect of continuous exposure to the marine atmosphere as well as intermittent exposure to sea-water (the so-called "tide-water" tests) is to be determined.

Surface treatment for improving the durability of magnesium.—The ultimate aim in this investigation is to produce a tightly adherent surface film, highly impervious to corrosive agents, particularly chlorides, to which paint and other applied coatings will adhere over long periods of time without peeling or flaking. Anodic treatment in a dichromate-phosphate bath by the method developed in cooperation with the Bureau of Aeronautics, according to repeated laboratory tests at the National Bureau of Standards, continues to be the preferred method for the surface treatment of magnesium and its alloys. Studies on the improvement of the anodic treatment have been continued, and the

results have indicated certain modifications by which further improvement appears possible. "Sealing" of the pores in the anodic film after it has been formed is important to produce a highly impervious film. This may be accomplished either by chemical means or by immersion in a hot oil or resin bath. Tests along this line are continuing. Initial cleaning before anodic treatment is also important in obtaining a film on the treated specimen of superior resistance. Tests on paint adherence as affected by the sealing treatment and other surface characteristics are in progress in the laboratory and on the outdoor exposure rack.

Sub-zero temperature and aircraft metals.—The original program, undertaken in cooperation with the Bureau of Aeronautics, has been completed and a report rendered, copies of which are available to all interested Government agencies. The only important adverse effect of low temperature, down to −80° C., is the decreased impact resistance of ferritic steels, which is in marked contrast to the aluminum alloys and the austenitic steels. Study of the factors responsible for this lowered impact resistance of ferritic steels is being continued with the aim of reducing and possibly eliminating the effect by suitable initial heat treatment of the steel. The investigation has been extended to include a study of the impact resistance at low temperatures of welded joints in steel members.

Elastic properties of high-strength aircraft metals.—The elastic properties of metals which owe their high-strength properties to strengthening by cold working are only nominal and vary greatly with the precision of the method used for their determination. An outstanding example is austenitic steel, such as 18–8 stainless steel, which because of its high corrosion resistance is favored for many important uses in aircraft. The method used in this work is essentially an "over-load" or "proof-stress" method, consisting in the determination of yield strength after various degrees of cold working by stretching immediately prior to testing. A rise in proof stress with increase in prior cold work is indicative of an improvement in the material, and vice versa for a decrease in proof stress. A report summarizing this phase of the work will be forthcoming shortly. Hysteresis measurements, such as those which may be obtained in the ordinary tensile-testing machine, are now in progress.

Structural changes in aircraft metals occurring as a result of service stressing.—The principal aim in this investigation is expressed in the question, Does continued fatigue-stressing below the endurance limit adversely affect aircraft metals? The widely used aluminum propeller alloy, 25S, is the material used in this study. A variety of approaches to the problem have been made, some of which were abandoned at early stages for more promising ones. The project is still in the stage of attempts to detect *significant* changes (other than crack formation and propagation) in physical properties, microstructure, and X-ray diffraction pattern as results of continued repeated stressing in the range of maximum fibre stress from 5,000 to 26,000 pounds per square inch. Up to the present no nondestructive method of inspection has been found which shows a significant difference between the metal not stressed and the same metal after it has been subjected to fatigue stressing. Special mention may be made of the failure to detect a lowering of impact resistance which could be attributed to prior fatigue stressing.

Propeller materials.—The possible deleterious effect of fabrication defects on the endurance properties of steel used in hollow steel propellers merits serious study. Also, the influence on the endurance of propellers of surface coatings, such as chromium plating as a finish, should not be overlooked.

The fatigue limit of such steel is approximately one-half of the tensile strength, which is considered to be normal for this material. Determinations of the fatigue limit of sound weld metal showed this to be about 60 percent of that of the parent metal. Scaling and surface decarburizing, such as may be present accidentally on the inside of the welded structure and cannot be removed, reduced the fatigue limit to one-half that of the polished steel, i. e., not much below that of the weld metal. The effect of accidental defects in the weld is variable; such defects may cause a very sharp reduction in the fatigue limit of the weld metal.

The effect of chromium plating varies with the condition of the steel and thickness of the plating. Specimens of normalized steel (previously polished) bearing relatively thick coatings showed no significant reduction in fatigue limit and a thinner coating had only a slightly greater effect. On specimens of the same steel in quenched-and-tempered condition, however, a reduction in fatigue limit was noted, which appeared to be of more significance and was greater for a very thin coating than for a coating ten times as thick, the plating in each case being applied directly to the previously polished steel. The use of a nickel "under coat," in accordance with commercial usage, prior to plating the quenched-and-tempered steel, gave similar results. The subject is receiving further study.

Further study of the unusual structural features previously reported for aluminum-alloy propeller blades has failed to show that any practical significance can be attached to them.

Miscellaneous.—The fact is well established that the corrosion resistance of many of the aluminum alloys which are strengthened by heat treatment is dependent in large measure upon the control of the conditions of heat treatment. A simple rapid test to determine in advance of service whether structural materials of this

kind have been suitably heat-treated so as to develop maximum corrosion resistance should serve a very useful purpose. A study is being made of a proposed method, the essential feature of which is a determination of the solution potential of the material under consideration.

A relatively inexpensive method of preparing small fittings of unusual shape is to use transverse sections of an extruded shape of the proper size and contour. A study of extruded aluminum fittings made in this manner is under way, with a two-fold purpose, namely, (a) the improvement of such fittings with respect to certain features which have not proved entirely satisfactory under all service conditions, and (b) the determination of the practical significance of certain suspected structural features.

The need for a certain degree of ductility in a structural member, as in an aircraft assembly, is well recognized. The amount and the manner in which it is specified are, however, matters on which difference of opinion exists. Determinations of the ductility of various structural steels under various conditions of stress application have been continued, in cooperation with the Bureau of Aeronautics of the Navy. Interpretations as to the practical significance of differences in this property observed under various conditions are yet to be made.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The problems under the cognizance of this subcommittee during the past year which are being investigated at the National Bureau of Standards include the development of a flexible substitute for glass and the development of substitutes for linen webbing and silk shroud lines for parachutes. Consideration has also been given to the possibilities of plastics as a material for aircraft structures and to the adequacy of thermal and acoustical insulation.

Development of flexible substitute for glass.—Commercial and experimental transparent plastics which have been investigated to determine their suitability for aircraft windshields and windows include cellulose acetate, acrylate resins, cellulose nitrate, ethylcellulose, vinyl chloride-acetate, vinyl acetal, glyceryl-phthalate, styrene, phenol-formaldehyde, and cellulose acetobutyrate.

The tests included light transmission, haziness, distortion, resistance to weathering, scratch and indentation hardnesses, impact strength, dimensional stability, resistance to water and various cleaning fluids, bursting strength at normal and low temperatures, and flammability.

The two types of transparent plastics which are now in use on aircraft, namely, cellulose acetate and acrylate resin, were found to have certain defects which, it is believed, can be overcome in part by suitable modification of the composition and processing of the material.

Cellulose-acetate plastic was found to have excellent impact strength, bursting strength, and flexibility, but the commercial products tested varied considerably in resistance to weathering and were all subject to marked shrinkage in one year's time. The shrinkage produces warping and sets up strains in the plastic sheets, which cause them to craze and crack. These strains are believed to be the cause of the spontaneous cracking of cellulose-acetate windshields after they have been in service for six months or longer. This is particularly true of windshields which are exposed to low temperatures, as by ascent to high altitudes, as additional strains are thereby introduced in the windshield because of thermal contraction. Considerable variation was observed in the weathering resistance between cellulose-acetate sheets received from different manufacturers and also between different lots of the material from the same manufacturer.

The acrylate-resin plastic was found to be remarkably transparent, more stable to light and weathering, and more resistant to scratching than cellulose acetate, but its impact strength and flexibility are much poorer. Surface crazing of the acrylate resins was noted after one year's exposure on the roof and also after storage for a similar period. It is claimed, however, that a method of processing has been developed which eliminates this tendency to craze. Further tests on modified samples of both cellulose acetate and acrylate resins are in progress to determine whether more uniformly durable products than have been on the market to date can be made available to the aircraft industry.

Certain of the other materials, which are not now commercially available, appear very promising.

Tests for impact resistance were developed on a scale commensurate with service conditions. Soft rubber balls, five inches in diameter, loaded to weigh three pounds, were fired from guns at the Naval Proving Grounds. The muzzle velocity was approximately 300 feet per second. No material, whether plastic or laminated glass, was found able to withstand a direct hit with such a projectile. The experimental pieces were, of course, limited as to weight and thickness by practical considerations of airplane design. It was therefore concluded that the windshield alone cannot be regarded as a protection against ducks.

Substitute for linen webbing.—An all-cotton webbing which meets the requirements for breaking strength, weight, width, and thickness contained in U. S. Army Specification No. 15–11–D for linen webbing has been produced commercially. While the construction is not identical with that of the Type-G webbing, the cotton webbing appears to be a satisfactory substitute.

Substitute for silk shroud lines.—Attempts to make shroud lines from some material other than silk have not been successful to date. Whether cotton or rayon was used, the strength-weight ratio of the line has not equalled that obtainable with silk. Experiments are being continued to obtain information on the effect of variations in the construction of the line.

Development of plastic material for aircraft structures.—A survey of the literature on this subject was completed and a report presented to the Committee. The report contains data on density, tensile and compressive strengths, modulus of elasticity, fatigue, energy absorption, corrosion, and methods of fabrication. The Committee is now studying this report with a view to deciding whether or not to go further into the matter.

Materials for acoustical and thermal insulation.—A report bringing together some of the information available on this subject has been presented to the Committee. Plans have been made to ascertain the practical importance of this subject, and upon the answer to this question will depend future developments.

REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Applied loads on airplane structures—gust loads.—Coordinated measurements of acceleration and air speed on transport airplanes have been continued during the past year, and the total flying time represented on the records has been extended to over 30,000 hours. The maximum accelerations previously recorded have not, however, been exceeded and the maximum effective gust velocities for normal transport operations remain at ±35 feet per second.

Gust research.—The measurements of gust intensities and gradients on light airplanes, begun last year, have been continued and the data greatly extended. The new results do not invalidate the previous tentative conclusions, that in stable atmospheric conditions with large wind gradients, vertical gust velocities of the order of 30 feet per second are reached in a horizontal distance of about 100 feet and that the gust gradient increases with decreasing gust intensity.

Surveys of cumulus types of clouds indicate, in general, stronger downward-acting than upward-acting gusts. On one occasion a downward gust of 53 feet per second, which reached maximum intensity in a distance of 53 feet, was experienced.

Gust tunnel.—During the past year an apparatus for catapulting dynamically scaled models through artificial gusts has been developed to the point of satisfactory operation. In this apparatus the model is launched into a condition of steady glide, following which it flies through an air jet whose angle relative to the flight path can be controlled. The model carries a small optically recording accelerometer, and as it flies through the gust the acceleration is recorded and synchronized with external photographic measurements of the speed, path angle, and attitude angle.

Although this equipment is not ideally suited to the investigation of some of the important fundamental problems of unsteady flow, it can be used and was designed for the direct determination of the effects of changes in the several airplane and gust variables on the airplane motion and wing loads. This function is justification for the equipment in view of the rapid trend toward larger transport airplanes, to which the statistical data obtained on past and present types of airplanes do not apply.

Gust-relief devices.—A preliminary analytical study of the merit of two devices for reducing accelerations due to gusts has been made. The more effective arrangement appears to be a trailing-edge flap operated by a small vane located somewhat ahead of the wing. This arrangement responds more quickly and reduces the acceleration further than the other device studied, which was simply a mass-overbalanced flap.

Load distribution.—The results of a previously reported investigation of the span-load distribution on wings with partial-span flaps have been published as Technical Report No. 585. This report includes a simple set of computing forms for determining the distribution by the Lotz method with sufficient harmonics retained for good precision. The work on wings with partial-span flaps has been extended to include the calculation of the angle of zero lift, the pitching moment, and the induced drag. Wing models are now being constructed for investigation to provide data for comparison with the calculations.

Several pressure-distribution tests have been made in the 7- by 10-foot wind tunnel of wings with various flap arrangements, including Fowler flaps with chords 30 and 40 per cent of the wing chord.

Several reports describing investigations conducted prior to this year have been issued and include a report on pressure-distribution measurements on an O–2H observation airplane in flight (Technical Report No. 590), a report presenting an empirical method for determining tip corrections to the theoretical span-load distribution (Technical Note No. 606), and a report on the theoretical span loading and moments of tapered wings produced by aileron deflection (Technical Note No. 589).

Fuel tank vents.—During a dive from high altitudes the pressure changes rapidly on the outside of an airplane. Unless the venting tubes to the fuel tanks and plugs are of the correct size, a pressure difference may be built up that will be sufficient to collapse the fuel tanks or plugs.

The Committee has been requested by the Bureau of Aeronautics, Navy Department, to investigate these pressure differences for a range of diameters and lengths of vent tubes. Apparatus has been assembled in the laboratory that makes possible the rapid determination of the pressure difference between a tank of given volume and the atmosphere during a dive. The laboratory tests have been made at constant temperature, as calculations show that this does not introduce an appreciable error.

Tests have been made for terminal velocities of 300, 400, and 500 miles per hour for dives starting at 10,000 to 40,000 feet altitude with float and tank volumes from 10 to 60 cubic feet. Several lengths of vent tubes 1.5 inches in diameter and 0.75 inch in diameter have been investigated. Pressure differences of 10.5 pounds per square inch have been recorded with a tube 0.5 inch in diameter and 12 feet long.

Stressed-Skin Design—stress analysis of beams with shear deformation of the flanges.—The rapidly increasing size of aircraft structures is forcing designers to rely increasingly, for economic reasons, on mathematical stress analysis rather than on static tests. It is well known that the classic methods of analysis are not always sufficiently accurate and efforts are being made to correct these methods.

As a step in this direction, the bending action of box beams such as airplane wings has been examined. It has been realized for some time that the flanges of such beams deform sufficiently under shear stress to alter the stress distribution materially. The mathematical theory of this action has been developed to the point of practical applicability and has been partially verified by tests. Further tests are under way to determine under what conditions the theory can be used without modification and, for cases in which modifications are necessary, to lead over into the range of the classic engineering theory of bending.

Strength of stiffeners.—A theory for primary failure of straight centrally loaded columns has been published as Technical Report No. 582. In the report the theory for twisting failure of open-section stiffeners, as presented by Herbert Wagner (Technical Memorandums Nos. 807 and 784), has been elaborated to include the twisting failure of open-section stiffeners attached to a skin, with stresses carried above the elastic range. An illustrative computation of the column curve for the twisting failure of an I-section skin-stiffener combination is also included.

Work is being continued on the twisting failure of other types of stiffener sections, notably the Z section and the U section, with and without flanged edges. Consideration is being given to the manner of shift of the axis of rotation in twisting failure, both in and above the elastic range, in order to establish the extent of refinement necessary for practical application.

Besides the study of twisting failure, which is a primary failure, the local failure of various types of stiffener sections is being investigated, and the theoretical strength curves are being compared with such experimental data as become available from time to time.

Stability of structural systems.—A report has been prepared and published as Technical Note No. 617 dealing with the stability criterion for structural systems. The Hardy Cross method of moment distribution is employed. In order to simplify the application of the stability criterion, detailed tables are given for the ready evaluation of the stiffness and carry-over factors. Sample problems are also included to illustrate the use of the method.

NATIONAL BUREAU OF STANDARDS

Tubes under loads other than torsion.—Considerable time has been spent during the year in revising and bringing into conformity with latest Navy Department specifications a report which has been written on the fixation of struts; that is, the column strength of tubing elastically restrained at the ends. This report is now completed and will be published by the National Advisory Committee for Aeronautics as a technical report. It gives the column strength of chromium-molybdenum steel, 17ST aluminum alloy, stainless steel, and heat-treated chromium-molybdenum-steel tubing, and suggests a method by which planar trusses that are continuous at the joints may be analyzed and designed for stability. Two numerical examples are given.

In order to determine the minimum ratio of slenderness below which thin tubes fail by crinkling rather than as columns, and to determine the crinkling strength, tests of short tubes must be made under axial load. The crinkling strength under axial load of relatively short specimens of round 17ST aluminum-alloy tubing has been determined for values of the diameter-thickness ratio approximately from 15 to 100. Work is in progress and has been almost completed to determine the crinkling strength of chromium-molybdenum-steel tubing.

The modulus of rupture of round 17ST aluminum-alloy tubing has been determined for values of the diameter-thickness ratio approximately from 15 to 100. This has been done under third-point loading with the load applied (1) in such a way that failure occurred in the free length between loads, and (2) in such a way that failure occurred under a load. The latter method of loading simulates practical conditions occasionally encountered under which the load is applied

through a compression member tending to dent the tube. Two empirical formulas involving the tensile yield strength of the tube material and the dimensions of the tube were derived to describe the modulus of rupture for the two series of tests.

The modulus of rupture obtained with the first method of loading does not depend to any marked extent on the position of the loading points, and the empirical formula for this method of loading may be used with safety whenever the maximum bending moment occurs in the free length of tube between loading points (including supports). The results are conservative for all other cases except in those relatively few instances in which the load is applied through a compression member tending to dent the tube. Under these conditions the empirical formula obtained from the tests with the second method of load should be used. The results of the second series of tests can be extended rationally to apply to other than third-point loading.

Work is in progress and has almost been completed to determine the modulus of rupture of round chromium-molybdenum-steel tubing under the same conditions of test as obtained for the 17ST aluminum-alloy tubing.

Determination of elastic constants on stainless-steel sheet material.—A study was made of the elastic properties of stainless-steel sheet of three thicknesses (0.007, 0.016, and 0.022 inch) in order to determine effective values of Young's modulus and of Poisson's ratio which could later be used in calculating stresses from the deformation under load of a model structure of this material.

The variation of Poisson's ratio and of Young's modulus with stress, sheet thickness, direction of rolling, and prestressing was measured by cutting tensile specimens in the direction of rolling and at right angles to that direction and measuring the ratio of transverse strain to axial strain with a set of four pairs of Tuckerman optical strain gages suitably placed to eliminate the effects of nonuniformity of stress distribution.

The values of Poisson's ratio were found to range from about 0.2 to 0.3. On the 0.007-inch specimen the Poisson's ratio in the direction of rolling was about 0.27, while at right angles to that direction it was only about 0.21. In some cases a considerable difference in values was found for the second run as compared to the first, showing the effect of prestressing on the elastic properties of the material.

Large variations in the value of Young's modulus with direction of rolling, sheet thickness, and stress were also found. In the case of the 0.007-inch specimens tested in the direction of rolling the Young's modulus dropped from around 28.5 10^6 pounds per square inch at a stress of around 5,000 pounds per square inch to a value less than 26.0 10^6 pounds per square inch at a stress of around 30,000 pounds per square inch.

The test results indicated the anisotropy of the stainless-steel sheet material. Stresses determined from strain measurements on a model constructed from such material would be subject to a probable error of several percent due to the variations in elastic properties alone.

Flat plates under normal pressure.—Experimental work was confined to tests of circular plates under normal pressure. The stress-strain curve of the material in the center of the plate was derived from the measured strains and the measured contours under load for two of the plates. In both cases the stress-strain curve obtained was found to differ from the tensile stress-strain curve of a coupon cut from the plate in that the stress continued to rise after passing the knee of the stress-strain curve; the mechanism of yielding in bilateral tension seemed to be different from that in straight tension.

The experimental work was paralleled by an extension of Stewart Way's analysis of clamped circular plates of medium thickness under normal pressure to greater deflections than the deflections of 1.2 times the thickness of the plate to which Way carried his tables. The deflections in the present plates amounted to about four times the plate thickness before yielding became appreciable. With the derivation of the curves of maximum stress and of deflection at the center of this order it will be possible to make an instructive comparison between the observed and the calculated deformation of circular flat plates, which it is hoped will lead to an understanding of the yielding in the rectangular plates also.

Inelastic behavior of duralumin and alloy steels in tension and compression.—The investigation of stress-strain curves of sheet material in tension and compression has been continued. A large number of tensile and "pack" compressive tests have been made on specimens cut with and across the direction of rolling from sheet ranging in thickness from 0.032 to 0.081 inch. Stress-strain curves have been obtained for aluminum alloys 17ST, 24ST, 24SRT, Alclad 17ST, and Alclad 24 ST. The difference in yield strength in compression as compared to tension was found to be of the order of 10 to 15 percent. The data suggest that the compressive yield strength of sheet material in the direction of rolling can, in general, be approximated roughly by the tensile yield strength at right angles to that direction, and vice versa.

The accuracy of the pack compression test was investigated by comparing the stress-strain curves obtained on solid specimens of cold-rolled steel, aluminum alloy, and brass 0.7 by 0.7 inch in section, with stress-

strain curves from pack compression tests on packs built up from leaves cut from the same bar stock. The two sets of stress-strain curves were found to agree within ±2 percent.

The pack compression tests on 24SRT aluminum alloy had shown a value of Young's modulus which was consistently higher by about 3 percent than the Young's modulus in tension. This difference could not be ascribed to errors in the compression tests. Preliminary tests indicated it to be due to a continuous increase in the slope of the stress-strain curve in passing from small tensile stresses through zero to small compressive stresses.

Tubes with torsional loads.—The report on torsion tests of 61 chromium-molybdenum-steel tubes and of 102 17ST aluminum-alloy tubes was completed and will be published as Technical Report No. 601 of the National Advisory Committee for Aeronautics.

A comparison of the empirical formulas proposed in this report with the torsional strength of tubes of 17ST and 51SW aluminum alloy as tested at the Aluminum Research Laboratories showed close agreement, although the tubes tested by the Aluminum Research Laboratories were considerably shorter and in the case of the 51SW material had considerably different mechanical properties than the tubes tested at this Bureau. The agreement may be ascribed to the use in the empirical formulas of ratios involving the tensile properties of the tube material.

Beams and stressed-skin research.—The program on wing beams has been continued with the completion of tests under axial load, transverse load, combined axial and transverse loads, of eight wing-beam specimens of aluminum alloy with an I-type section having tilted flanges. Failure in these beams occurred by local instability of one of the flanges. The measured strains and deflections are being analyzed with the help of compressive stress-strain curves for the flange material which were obtained by the pack method. Failure of the combined-load specimens occurred at a flange stress calculated from the loads which ranged from 34,700 to 36,400 pounds per square inch.

The analysis of the data obtained on the two sheet-stringer panels tested in end compression at the National Bureau of Standards has been completed. Comparison with the results of similar tests at the Navy Model Basin on panels of the same design showed good agreement for the load carried by the sheet at failure. The load carried by stringers at failure was found to be about 10 to 20 percent lower for two of the specimens tested at the Model Basin. This relative loss in strength is probably due to the difference in end restraint, the flat end condition used at the Model Basin providing less restraint against buckling than the casting of the ends in Wood's metal used at the National Bureau of Standards.

The measured strain distribution in the sheet of the two panels tested at the National Bureau of Standards and the measured buckle shape were compared with the deformation calculated from approximate theories developed by S. Timoshenko, by J. M. Frankland, and by K. Marguerre. None of the approximate theories was found to agree accurately with observed deformations. The deflections of the buckled sheet were best described by Timoshenko's theory, the axial strains were about equally well described by all three theories, the transverse strains were best described by Frankland's theory, and the sheet load was best described by Marguerre's theory.

The analysis of the deformation of the stringers in the sheet-stringer panels was confined to a series of plots of deformation against deformation over load in accordance with Southwell's method. If the deformation plotted leads to an instability of the type to which Southwell's relation applies, all points will lie on a straight line with a slope equal to the elastic buckling load. Excellent straight lines could be obtained for some of the stringer twists as measured by the rotation of pointers mounted on the stringer, the slope of the lines being in close agreement with the observed buckling load. The agreement was less satisfactory for plots of other deformations. The lack of general agreement is not surprising, since a proof for the validity of Southwell's method has been given so far only for the column failure of beams under eccentric axial load and under certain combinations of axial and transverse loads.

Eighteen sheet-stringer panels are being fabricated at the Naval Aircraft Factory for the investigation of the effect on the compressive strength of such panels of rivet spacing and spot-spacing. The panels will be 12 and 18 inches long and will consist of three Z-type stringers fastened to the sheet by rivets or spots spaced an amount ranging from ½ to 4 inches. The spacing between stringers, the sheet thickness, and the spacing between rivets or spots will be varied to explore the effect of rivet spacing on both the buckling of the sheet between rivets and on the effective width of the sheet between stringers.

Airplane vibration.—Close cooperation was maintained with the Bureau of Aeronautics of the Navy Department in its program on airplane vibration. The National Bureau of Standards participated actively in a number of conferences at which methods were discussed for recording the readings of vibration pick-ups and of strain pick-ups mounted on various portions of an airplane in flight.

An important part of the program is the development of dynamic-strain pick-ups suitable for attachment to

the structural parts of an airplane. In connection with this work a number of special strain pick-ups have been built by the Sperry Gyroscope Company which embodied a principle of inertia compensation suggested by William M. Bleakney, of the Engineering Mechanics Section of this Bureau. A description of this principle has appeared in the Journal of Research of the National Bureau of Standards for June 1937 under the title "Compensation of Strain Gages of Vibration and Impact," by William M. Bleakney. Three of the experimental pick-ups built by the Sperry Gyroscope Company were tested for compensation and for ruggedness of construction on a device subjecting them to accelerations up to 50 times gravity with negligible strain. Compensation for inertia forces adequate for present applications was obtained on one of these after a number of small adjustments had been made. The calibrations also suggested a number of changes in the design of the gage which would probably improve its operation.

A second type of strain pick-up on which considerable work was done at the Bureau is the strain pick-up of the carbon-resistance type developed by A. V. de-Forest. Static and dynamic calibrations were made on 20 carbon resistance strips, 5 of them of the "granular" type used at the Hamilton Standard Propeller Company, and the remaining 15 of the so-called "Ess-strip" type. A report describing the results of these tests in detail has been forwarded to the Bureau of Aeronautics of the Navy Department. The report gives quantitative results for the effect of frequency, strain amplitude, time under load, and temperature on the calibration of a number of these strain pick-ups.

The best dynamic characteristics were found for the gages of the "Ess-strip" type. These gages showed a resistance amplitude that was nearly proportional to the strain amplitude up to strains of 0.001 (corresponding to stresses of about 10,000 pounds per square inch in aluminum alloy). The calibration factor calculated by dividing the constant of proportionality by the direct-current resistance of the gage was independent of frequency between 30 and 100 cycles per second within ± 10 percent, independent of temperature between $-10°$ C. and 40° C. within ± 10 percent, independent of time for one day within ± 5 percent and for 40 days within ± 9 percent.

The static calibration tests, which were confined to gages of the "Ess-strip" type, gave calibration factors ranging from 40 percent below to 35 percent above the dynamic calibration factors. The effect of temperature variations and of time under load were found to be sufficient to render this type of strain gage very much inferior to accepted gages such as the Tuckerman optical strain gage or the Huggenberger extensometer in those cases where static strains on a large structure are to be measured.

The dynamic calibrations of "Ess-strips," which were made by attaching the gage to a propeller blade and then vibrating this blade in resonance, had indicated the need for a calibrator that would subject the strips to uniform sinusoidal strains of sufficient amplitude and of a frequency that could be varied over a wider range than the restricted number of resonance frequencies (30 to 100 cycles per second) that could be set up in the propeller blades. A device was accordingly designed for calibrating dynamic-strain gages up to 8 inches in length by subjecting them to uniform sinusoidal strains up to 0.001 at frequencies ranging from 10 to 200 cycles per second. This device is now being constructed.

Strength of riveted joints in aluminum alloy.—The investigation described in Technical Note 585 of the National Advisory Committee for Aeronautics has been extended to joints in which combinations of the following alloys were used: rivets, A17ST, 53SW, 53ST, and 24ST; and sheet, 24ST, 24SRT, and Alclad 24ST.

In accordance with the suggestions of manufacturers, tests have been made to determine whether the results previously obtained on 0.25-inch rivets are applicable to rivets of other sizes. Single shear and double shear tests made so far on rivets ranging from $\frac{3}{32}$ to $\frac{5}{16}$ inch in diameter indicate that for practical purposes there is no difference between the results obtained on the various sizes. The driving stress required to form a flat head of a given size was found to increase slightly with the diameter of the rivet, but this tendency was not observed for button heads.

Tests to determine the effect of aging upon the driving stress required to form the head, the shearing strength of rivets of the various alloys, and the mechanical properties of rivet wire are being carried out.

To supply information needed by the industry on riveted joints of the flush type, specifications for joints to be made by manufacturers have been prepared and distributed. Several sets of specimens have been received, and these are now being tested. Other flush riveted specimens are being made at this Bureau.

A set of fixtures has been constructed for driving rivets by means of a pneumatic hammer in a manner which minimizes the personal element in the heading process.

Investigation of fatigue resistance of fabricated structural elements of aircraft.—The fatigue test on the rear upper wing beam of a BF2C–1 airplane was followed by a similar test on the front beam of the same wing cell. The test was carried to failure at a nominal stress amplitude of about 5,700 pounds per square inch, as compared to a nominal stress amplitude of about 8,500 pounds per square inch for the first test. After about

2,900,000 cycles one flange parted with a sharp report at a section where a rib attachment had been riveted to the flange. Several other cracks were found in the same flange, and a large crack was found in the web just outside one terminal attachment. Comparison of the stress history with the endurance curve of similar material indicated a stress concentration factor of about 3.7. This is considerably higher than the stress concentration factor of about 3 derived for the first test, and indicates that the fatigue limit of the fabricated structure may be well below one-third the fatigue limit of the material, perhaps as low as a nominal stress of 4,000 pounds per square inch.

Two complete sets of BF2C–1 wings have been supplied by the Navy Department for the fatigue tests. The wing beams have been removed from these wings, and a method of cutting them has been devised which will give eight wing-beam specimens of sufficiently uniform section for the tests. It is planned to test these specimens at different amplitudes of nominal stress in order to obtain a sufficient number of values of stress against cycles to failure to draw a S–N curve for the fabricated wing beam, which may then be compared with the S–N curve of the wing-beam material. The first of these eight specimens is being set up for test in the fatigue machine.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. Code, title 50, sec. 151). The Committee is composed of fifteen members appointed by the President and serving as such without compensation. The law provides that the members shall include two representatives each from the War and Navy Departments and one each from the Smithsonian Institution, the Weather Bureau, and the National Bureau of Standards, together with not more than eight additional persons "who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." One of these eight is a representative of the Bureau of Air Commerce of the Department of Commerce. Under the rules and regulations governing the work of the Committee as approved by the President the Chairman and Vice Chairman of the Committee are elected annually. At the meeting held on October 21, 1937, Dr. Joseph S. Ames was reelected Chairman for the ensuing year and Dr. David W. Taylor was reelected Vice Chairman.

Dr. Joseph S. Ames resigned as Chairman of the Executive Committee in April 1937, a position he had filled continuously since October 9, 1919. At the meeting held on April 22, 1937, Dr. Willis Ray Gregg, Chief of the Weather Bureau, was elected to fill out Dr. Ames' unexpired term as Chairman of the Executive Committee. At the meeting held on October 21, 1937, Dr. Gregg was elected Chairman of the Executive Committee for the ensuing year and Dr. William P. MacCracken Vice Chairman of the Executive Committee. Dr. David W. Taylor had served as Vice Chairman of the Executive Committee since that position was created in 1927. He remains Vice Chairman of the main Committee.

During the past year there was one change in the membership of the main Committee. Dr. Fred D. Fagg, Jr., who had succeeded Honorable Eugene L. Vidal as Director of Air Commerce of the Department of Commerce, was, on April 23, 1937, appointed by the President to succeed Mr. Vidal as a member of the National Advisory Committee for Aeronautics.

The executive offices of the Committee, including its offices of aeronautical intelligence and aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. Scientific and technical data on aeronautics secured from all parts of the world are classified, catalogued, and disseminated by this office.

To assist in the collection of current scientific and technical information and data, the Committee maintains a technical assistant in Europe with headquarters at the American Embassy in Paris.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the inventions section received for consideration 1,475 new submissions. It conducted the necessary correspondence and granted interviews as requested by the inventors. Approximately six percent of the new submissions were received through the Aeronautical Patents and Design Board. In those cases reports on the merits of the submissions were made to that board, and in all other cases replies were submitted directly to the inventors.

AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

In continuation of the plan initiated as a result of recommendation of the Federal Aviation Commission, a special allotment of $25,000 was made available from the Committee's funds during the fiscal year 1937 for aeronautical research in educational institutions. Under this allotment eleven contracts were made during the year with five universities and technical schools, for special investigations and reports on the basis of the probable usefulness and value of the information to aeronautics.

Several of the papers prepared under contracts made the preceding year have been published by the Committee, while others have supplied information of value as a basis for further research either at the Committee's laboratory or elsewhere. The papers received under contracts which have been published by the Committee include one technical report and three technical notes. In addition, one paper has been issued in advance confidential form to American manufacturers.

COOPERATION WITH THE AVIATION INDUSTRY

The Committee, in the preparation of its program of research, makes provision for the requirements of the aviation industry as to problems to be investigated, both in connection with design and operation. The aircraft manufacturers and operators bring their problems to the Committee's attention as they arise, either by correspondence or by personal contacts and informal conferences. Advantage is taken by the Committee of every opportunity to obtain suggestions and recommendations from representatives of the industry as to investigations which are of particular importance to them. When the need arises in connection with any particular problem of the industry it is the policy of the Committee to call a special conference, or, as previously stated, to establish a special subcommittee, including in either case representation from the industry.

Realizing that frequently the value of information is greatly enhanced by its prompt availability, every effort is made to place in the hands of the industry at the earliest possible date the results of researches that are of particular interest to commercial aeronautics. It sometimes appears, in the course of an extensive investigation being conducted by the Committee, that the results so far obtained will be of special interest and value to the aircraft industry if made available immediately. In such cases the Committee issues the information in advance confidential form to American manufacturers and the Government services.

Some of the subjects on which results have been released in this manner during the past year are the prevention of ice formation on propellers; the characteristics of related forward camber airfoils, from tests in the variable-density wind tunnel; the characteristics of tapered wings having N. A. C. A. mean lines; the characteristics of tandem air propellers, as investigated by Stanford University under contract with the Committee; wing-fuselage interference, including in the first report a comparison of conventional and airfoil-type fuselage combinations, and in the second report the characteristics of thirty combinations, from tests in the variable-density wind tunnel; transparent plastics for use on aircraft, as investigated by the National Bureau of Standards for the Committee; tricycle-type landing gears, including three phases of the subject—first, accelerations in landing, second, factors affecting the geometrical arrangement; and third, the stability of castering wheels; and the characteristics of tapered wings with ordinary ailerons and partial-span split flaps, as determined in wind-tunnel investigation.

Annual research conference.—As an important aid in keeping in close contact with the problems and needs of the aviation industry, the Committee holds each May at its laboratories at Langley Field an aircraft engineering research conference with representatives of aircraft manufacturers and operators. This conference was initiated in 1926, and has two principal purposes, as follows: First, to enable representatives of the industry to obtain first-hand information on the Committee's research facilities and the results obtained in its investigations; and, second, to afford them an opportunity to present to the Committee their suggestions for investigations to be included in the Committee's research program.

Owing to the large number of those who desired to attend, the conference for the past two years has been held on two days, the same program of discussions and demonstrations being followed both days. The dates of the 1937 conference were May 18 and 20.

Acting under authorization of Dr. Joseph S. Ames, Chairman of the National Advisory Committee for Aeronautics, who was prevented by illness from being present, Honorable Edward P. Warner, a member of the Committee and Chairman of the Committee on Aerodynamics, served as Chairman of the conference on May 18; and on May 20 Dr. Willis Ray Gregg, Chairman of the Executive Committee of the National Advisory Committee for Aeronautics, was Chairman. The Committee was represented on both days by officers and members, and on May 18 also by its Committees on Aerodynamics and Power Plants for Aircraft, and on the 20th by its Committee on Aircraft Structures and Materials and Subcommittee on Structural Loads and Methods of Structural Analysis.

At the morning session each day the principal investigations under way at the laboratory, both in aero-

dynamics and power plants, were explained by the engineers in charge of the work, and charts were exhibited showing some of the results obtained. The guests were then conducted on a tour of inspection of the laboratory and the research equipment was shown in operation.

In the afternoon six simultaneous conferences were held for the discussion of six different subjects, namely, airplane performance and design characteristics, aerodynamic efficiency and interference, cowling and cooling research, aircraft-engine research, seaplanes, and rotorplanes. At these conferences the results of the Committee's researches were presented in further detail, and suggestions were submitted by the representatives of the industry for problems to be added to the Committee's program. Each of these suggestions, according to its nature, was referred to the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, or the Subcommittee on Structural Loads and Methods of Structural Analysis and was considered by that committee in the preparation of the research program being carried on under its cognizance.

SUBCOMMITTEES

The Advisory Committee has organized four main standing technical committees, with subcommittees, for the purpose of supervising its work in their respective fields. The four main technical Committees on Aerodynamics, Power Plants for Aircraft, Aircraft Materials, and Aircraft Structures and their subcommittees supervise and direct the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies.

As previously stated, during the past year there has been a major change in the organization of the Committee's standing technical committees. The Committee on Aircraft Structures and Materials, which was one of the three principal technical committees, and two of its subcommittees, the Subcommittee on Structural Loads and Methods of Structural Analysis and the Subcommittee on Research Program on Monocoque Design, were discharged, and two new standing committees, the Committee on Aircraft Materials and the Committee on Aircraft Structures, were established, each with a status coordinate with that of the Committee on Aerodynamics and the Committee on Power Plants for Aircraft. The Subcommittee on Metals Used in Aircraft and the Subcommittee on Miscellaneous Materials and Accessories were retained as subcommittees of the new Committee on Aircraft Materials.

The work of the standing technical committees and subcommittees has been described in part I.

The organization of the committees and of the standing subcommittees is as follows:

COMMITTEE ON AERODYNAMICS

Hon. Edward P. Warner, Chairman.

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.

Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. L. J. Briggs, National Bureau of Standards.

Theophile dePort, Matériel Division, Army Air Corps, Wright Field.

Lt. Comdr. W. S. Diehl, United States Navy.

Dr. H. L. Dryden, National Bureau of Standards.

Lt. Col. O. P. Echols, Air Corps, United States Army, Matériel Division, Wright Field.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Lt. Comdr. L. M. Grant, United States Navy.

Dr. Willis Ray Gregg, United States Weather Bureau.

Lawrence V. Kerber, Bureau of Air Commerce, Department of Commerce.

Delbert M. Little, United States Weather Bureau.

Elton W. Miller, National Advisory Committee for Aeronautics.

Comdr. F. W. Pennoyer, Jr., United States Navy.

H. J. E. Reid, National Advisory Committee for Aeronautics.

Dr. David W. Taylor.

Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

SUBCOMMITTEE ON AIRSHIPS

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Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.

Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.

Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

Commander Garland Fulton, United States Navy.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Ralph H. Upson, Ann Arbor, Mich.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Dr. Willis Ray Gregg, United States Weather Bureau, Chairman.

Dr. W. J. Humphreys, United States Weather Bureau.

Dr. J. C. Hunsaker, Massachusetts Institute of Technology.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Delbert M. Little, United States Weather Bureau.

Dr. Charles F. Marvin.

Lt. Comdr. F. W. Reichelderfer, United States Navy, Naval Air Station, Lakehurst.

Dr. C. G. Rossby, Massachusetts Institute of Technology.

Maj. B. J. Sherry, United States Army, Signal Corps, War Department.

Eugene Sibley, Bureau of Air Commerce, Department of Commerce.

SUBCOMMITTEE ON SEAPLANES

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Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

Theophile dePort, Matériel Division, Army Air Corps, Wright Field.

Lt. Comdr. W. S. Diehl, United States Navy.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Jack T. Gray, Bureau of Air Commerce, Department of Commerce.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Lt. Comdr. A. O. Rule, United States Navy.

Starr Truscott, National Advisory Committee for Aeronautics.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

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Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.

Lt. Comdr. Rico Botta, United States Navy.

Dr. H. C. Dickinson, National Bureau of Standards.

John H. Geisse, Bureau of Air Commerce, Department of Commerce.

Carlton Kemper, National Advisory Committee for Aeronautics.

Gaylord W. Newton, Bureau of Air Commerce, Department of Commerce.

Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

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Dr. O. C. Bridgeman, National Bureau of Standards.

Lt. Comdr. James V. Carney, United States Navy.

H. K. Cummings, National Bureau of Standards.

L. S. Hobbs, The Pratt and Whitney Aircraft Company.

Robert V. Kerley, Matériel Division, Army Air Corps, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Gaylord W. Newton, Bureau of Air Commerce, Department of Commerce.

Arthur Nutt, Wright Aeronautical Corporation.

Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

Addison M. Rothrock, National Advisory Committee for Aeronautics.

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Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

S. K. Colby, Aluminum Co. of America.

Lt. Comdr. C. F. Cotton, United States Navy.

Edgar H. Dix, Jr., American Magnesium Corporation.

Warren E. Emley, National Bureau of Standards.

Comdr. Garland Fulton, United States Navy.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Jack T. Gray, Bureau of Air Commerce, Department of Commerce.

C. H. Helms, National Advisory Committee for Aeronautics.

J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

H. S. Rawdon, National Bureau of Standards.

E. C. Smith, Republic Steel Corporation.

Paul F. Voigt, Jr., Carnegie-Illinois Steel Corporation.

Hon. Edward P. Warner.

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C. H. Helms, National Advisory Committee for Aeronautics.

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Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

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G. W. Trayer, Forest Service, Department of Agriculture.

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Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.

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Eugene E. Lundquist, National Advisory Committee for Aeronautics.

Lt. Comdr. R. D. MacCart, United States Navy.

Prof. Joseph S. Newell, Massachusetts Institute of Technology.

Dr. Walter Ramberg, National Bureau of Standards.

Richard V. Rhode, National Advisory Committee for Aeronautics.

Edward I. Ryder, Bureau of Air Commerce, Department of Commerce.

R. L. Templin, Aluminum Company of America.

Dr. L. B. Tuckerman, National Bureau of Standards.

Hon. Edward P. Warner.

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Lt. Comdr. A. O. Rule, United States Navy.

J. T. Shumate, Bureau of Air Commerce, Department of Commerce.

Maj. Lowell H. Smith, Air Corps, United States Army.

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Brig. Gen. A. W. Robins, Air Corps, United States Army. Matériel Division, Wright Field.

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Dr. Willis Ray Gregg, United States Weather Bureau, Vice Chairman.

Miss M. M. Muller, Secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, Chairman.

Dr. David W. Taylor, Vice Chairman.

Dr. Willis Ray Gregg, United States Weather Bureau.

John F. Victory, Secretary.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft.

The following are lists of the publications issued:

LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

No.

577. Prechamber Compression-Ignition Engine Performance. By Charles S. Moore and John H. Collins, Jr., N. A. C. A.

578. Flight Measurements of the Dynamic Longitudinal Stability of Several Airplanes and a Correlation of the Measurements with Pilots' Observations of Handling Characteristics. By Hartley A. Soulé, N. A. C. A.

579. A Study of the Two-Control Operation of an Airplane. By Robert T. Jones, N. A. C. A.

580. Heat Transfer to Fuel Sprays Injected into Heated Gases. By Robert F. Selden and Robert C. Spencer, N. A. C. A.

581. Measurements of Intensity and Scale of Wind-Tunnel Turbulence and Their Relation to the Critical Reynolds Number of Spheres. By Hugh L. Dryden, G. B. Schubauer, W. C. Mock, Jr., and H. K. Skramstad, National Bureau of Standards.

582. A Theory for Primary Failure of Straight Centrally Loaded Columns. By Eugene E. Lundquist and Claude M. Fligg, N. A. C. A.

583. The Rolling Friction of Several Airplane Wheels and Tires and the Effect of Rolling Friction on Take-Off. By J. W. Wetmore, N. A. C. A.

584. Strength of Welded Aircraft Joints. By W. C. Brueggeman, National Bureau of Standards.

585. Span Load Distribution for Tapered Wings with Partial-Span Flaps. By H. A. Pearson, N. A. C. A.

586. Airfoil Section Characteristics as Affected by Variations of the Reynolds Number. By Eastman N. Jacobs and Albert Sherman, N. A. C. A.

587. Blower Cooling of Finned Cylinders. By Oscar W. Schey and Herman H. Ellerbrock, Jr., N. A. C. A.

588. Fuel Spray and Flame Formation in a Compression-Ignition Engine Employing Air Flow. By A. M. Rothrock and C. D. Waldron, N. A. C. A.

589. An Analysis of Lateral Stability in Power-Off Flight with Charts for Use in Design. By Charles H. Zimmerman, N. A. C. A.

590. Pressure-Distribution Measurements on an O-2H Airplane in Flight. By H. A. Pearson, N. A. C. A.

591. An Analytical and Experimental Study of the Effect of Periodic Blade Twist on the Thrust, Torque, and Flapping Motion of an Autogiro Rotor. By John B. Wheatley, N. A. C. A.

592. Full-Scale Tests of N. A. C. A. Cowlings. By Theodore Theodorsen, M. J. Brevoort, and George W. Stickle, N. A. C. A.

593. Cooling of Airplane Engines at Low Air Speeds. By Theodore Theodorsen, M. J. Brevoort, and George W. Stickle, N. A. C. A.

594. Characteristics of Six Propellers Including the High-Speed Range. By Theodore Theodorsen, George W. Stickle, and M. J. Brevoort, N. A. C. A.

595. Full-Scale Tests of a New Type N. A. C. A. Nose-Slot Cowling. By Theodore Theodorsen, M. J. Brevoort, George W. Stickle, and M. N. Gough, N. A. C. A.

596. Cooling Tests of a Single-Row Radial Engine with Several N. A. C. A. Cowlings. By M. J. Brevoort, George W. Stickle, and Herman H. Ellerbrock, Jr., N. A. C. A.

597. Air Propellers in Yaw. By E. P. Lesley, George F. Worley, and Stanley Moy, Stanford University.

598. Alternating-Current Equipment for the Measurement of Fluctuations of Air Speed in Turbulent Flow. By W. C. Mock, Jr., National Bureau of Standards.

599. Flight Tests of the Drag and Torque of the Propeller in Terminal-Velocity Dives. By Richard V. Rhode and Henry A. Pearson, N. A. C. A.

600. An Analysis of the Factors That Determine the Periodic Twist of an Autogiro Rotor Blade, with a Comparison of Predicted and Measured Results. By John B. Wheatley, N. A. C. A.

601. Torsion Tests of Tubes. By Ambrose H. Stang, Walter Ramberg, and Goldie Back, National Bureau of Standards.

602. Wind-Tunnel and Flight Tests of Slot-Lip Ailerons. By Joseph A. Shortal, N. A. C. A.

603. Wind-Tunnel Investigation of Wings with Ordinary Ailerons and Full-Span External-Airfoil Flaps. By Robert C. Platt and Joseph A. Shortal, N. A. C. A.

604. Pressure-Distribution Measurements at Large Angles of Pitch on Fins of Different Span-Chord Ratio on a 1/40-Scale Model of the U. S. Airship "Akron." By James G. McHugh, N. A. C. A.

605. Résumé and Analysis of N. A. C. A. Lateral Control Research. By Fred E. Weick and Robert T. Jones, N. A. C. A.
606. Electrical Thermometers for Aircraft. By John B. Peterson and S. H. J. Womack, National Bureau of Standards.
607. Spinning Characteristics of the XN2Y–1 Airplane Obtained from the Spinning Balance and Compared with Results from the Spinning Tunnel and from Flight Tests. By M. J. Bamber and R. O. House, N. A. C. A.
608. Stress Analysis of Beams with Shear Deformation of the Flanges. By Paul Kuhn, N. A. C. A.
609. Experimental Investigation of Wind-Tunnel Interference on the Downwash behind an Airfoil. By Abe Silverstein and S. Katzoff, N. A. C. A.
610. Tests of Related Forward-Camber Airfoils in the Variable-Density Wind Tunnel. By Eastman N. Jacobs, Robert M. Pinkerton, and Harry Greenberg, N. A. C. A.
611. Wind-Tunnel Investigation of Tapered Wings with Ordinary Ailerons and Partial-Span Split Flaps. By Carl J. Wenzinger, N. A. C. A.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

582. Analysis and Model Tests of Autogiro Jump Take-Off. By John B. Wheatley and Carlton Bioletti, N. A. C. A.
583. Mixture Distribution in a Single-Row Radial Engine. By Harold C. Gerrish and Fred Voss, N. A. C. A.
584. Effect of Several Factors on Cooling of a Radial Engine in Flight. By Oscar W. Schey and Benjamin Pinkel, N. A. C. A.
585. Mechanical Properties of Aluminum-Alloy Rivets. By Wm. C. Brueggeman, National Bureau of Standards.
586. The Reduction of Aileron Operating Force by Differential Linkage. By Robert T. Jones and Albert I. Nerken, N. A. C. A.
587. The Forces and Moments on Airplane Engine Mounts. By Philip Donely, N. A. C. A.
588. Strain Measurements on Small Duralumin Box Beams in Bending. By Paul Kuhn, N. A. C. A.
589. Theoretical Span Loading and Moments of Tapered Wings Produced by Aileron Deflection. By H. A. Pearson, N. A. C. A.
590. Hydrodynamic Tests in the N. A. C. A. Tank of a Model of the Hull of the Short Calcutta Flying Boat. By Kenneth E. Ward, N. A. C. A.
591. Full-Scale Span Load Distribution on a Tapered Wing with Split Flaps of Various Spans. By John F. Parsons and Abe Silverstein, N. A. C. A.
592. A Study of the Factors Affecting the Range of Airplanes. By David Biermann, N. A. C. A.
593. Pressure Drop in Tubing in Aircraft Instrument Installations. By W. A. Wildhack, National Bureau of Standards.
594. Tank Tests of Two Models of Flying-Boat Hulls to Determine the Effect of Ventilating the Step. By John R. Dawson, N. A. C. A.
595. Bending Tests of Circular Cylinders of Corrugated Aluminum-Alloy Sheet. By Alfred S. Niles, John C. Buckwalter, and Warren D. Reed, Stanford University.
596. Full-Scale Wind-Tunnel and Flight Tests of a Fairchild 22 Airplane Equipped with a Zap Flap and Zap Ailerons. By C. H. Dearborn and H. A. Soulé, N. A. C. A.
597. Notes on the Calculation of the Minimum Horizontal Tail Surface for Airplanes Equipped with Wing Flaps. By Hartley A. Soulé, N. A. C. A.
598. Wind-Tunnel Tests of a Clark Y Wing with "Maxwell" Leading-Edge Slots. By William E. Gauvain, N. A. C. A.
599. Charts Expressing the Time, Velocity, and Altitude Relations for an Airplane Diving in a Standard Atmosphere. By H. A. Pearson, N. A. C. A.
600. Discharge Characteristics of a Double Injection-Valve Single-Pump Injection System. By Dana W. Lee and E. T. Marsh, N. A. C. A.
601. The Lateral Instability of Deep Rectangular Beams. By C. Dimont and H. N. Hill, Aluminum Company of America.
602. Heat Transfer from Cylinders Having Closely Spaced Fins. By Arnold E. Biermann, N. A. C. A.
603. A Preliminary Study of Flame Propagation in a Spark-Ignition Engine. By A. M. Rothrock and R. C. Spencer, N. A. C. A.
604. Full-Scale Wind-Tunnel and Flight Tests of a Fairchild 22 Airplane Equipped with External-Airfoil Flaps. By Warren D. Reed and William C. Clay, N. A. C. A.
605. Noise from Propellers with Symmetrical Sections at Zero Blade Angle. By A. F. Deming, N. A. C. A.
606. Empirical Corrections to the Span Load Distribution at the Tip. By H. A. Pearson, N. A. C. A.
607. The Behavior of Thin-Wall Monocoque Cylinders Under Torsional Vibration. By Robert E. Pekelsma, University of Michigan.
608. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. I—Basic Loading Condition. By Oscar Seidman and A. I. Neihouse, N. A. C. A.
609. Considerations Affecting the Additional Weight Required in Mass Balance of Ailerons. By W. S. Diehl, Bureau of Aeronautics, Navy Department.
610. Effect of Air-Entry Angle on Performance of a 2-Stroke-Cycle Compression-Ignition Engine. By Sherod L. Earle and Francis J. Dutee, N. A. C. A.
611. The Sonic Altimeter for Aircraft. By C. S. Draper, Massachusetts Institute of Technology.
612. Spinning Characteristics of Wings. III—A Rectangular and a Tapered Clark Y Monoplane Wing with Rounded Tips. By M. J. Bamber and R. O. House, N. A. C. A.
613. The Effect of Curvature on the Transition from Laminar to Turbulent Boundary Layer. By Milton Clauser and Francis Clauser, California Institute of Technology.
614. Fuselage-Drag Tests in the Variable-Density Wind Tunnel: Streamline Bodies of Revolution, Fineness Ratio of 5. By Ira H. Abbott, N. A. C. A.
615. Motion of the Two-Control Airplane in Rectilinear Flight after Initial Disturbances with Introduction of Controls Following an Exponential Law. By Alexander Klemin, New York University.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

805. General Considerations on the Flow of Compressible Fluids. By L. Prandtl. Paper presented at Volta meeting in Italy, September 30 to October 6, 1935.
806. The Question of Spontaneous Wing Oscillations (Determination of Critical Velocity through Flight-Oscillation Tests). By B. v. Schlippe. From Luftfahrtforschung, February 20, 1936.
807. Torsion and Buckling of Open Sections. By Herbert Wagner. From the 25th anniversary number of the Technische Hochschule, Danzig 1904–1929.

808. High-Speed Wind Tunnels. By J. Ackeret. Paper presented at the fifth convention of the Volta Congress, Italy, September 30 to October 6, 1935.
809. Tests for the Determination of the Stress Condition in Tension Fields. By R. Lahde and H. Wagner. From Luftfahrtforschung, August 20, 1936.
810. Impact of a Vee-Type Seaplane on Water with Reference to Elasticity. By F. Weinig. From Luftfahrtforschung, May 20, 1936.
811. The Impact on Floats or Hulls During Landing as Affected by Bottom Width. By E. Mewes. From Luftfahrtforschung, May 20, 1936.
812. The Horsepower of Aircraft Engines and Their Maximum Frontal Area. By Michel Precoul. From L'Aéronautique, No. 207, August 1936.
813. The Cetene Scale and the Induction Period Preceding the Spontaneous Ignition of Diesel Fuels in Bombs. By M. N. Michailova and M. B. Neumann. From Comptes Rendus (Doklady) de l'Academie des Sciences de l'URSS, Vol. II (XI), No. 4 (90), 1936.
814. Experimental Studies of the Effective Width of Buckled Sheets. By R. Lahde and H. Wagner. From Luftfahrtforschung, July 20, 1936.
815. Automatic Stabilization. By Fr. Haus. From L'Aéronautique, March 1936.
816. The Gyroplane—Its Principles and Its Possibilities. By Louis Breguet. From Journees Techniques Internationales de l'Aéronautique, November 23–27, 1936.
817. The Stress Distribution in Shell Bodies and Wings as an Equilibrium Problem. By H. Wagner. From Luftfahrtforschung, September 20, 1936.
818. Valve-Spring Surge. By Willy Marti. Federal Polytechnic Institute of Zurich. 1935.
819. Experimental Apparatus for the Study of Propellers. By M. Panetti. From Experimental reports by the Aeronautical Laboratory of the Royal Engineering Institute of Turin, series 1.
820. Some Experiments on the Slipstream Effect. By C. Ferrari. From Experimental reports by the Aeronautical Laboratory of the Royal Engineering Institute of Turin, series 2.
821. On the Actual Loads on Airplane Landing Gears. By S. Shiskin. From Report No. 269, of the Central Aero-Hydrodynamical Institute, Moscow, 1936.
822. Turbulent Boundary Layer of an Airfoil. By K. Fediaevsky. From Report No. 282, of the Central Aero-Hydrodynamical Institute, Moscow, 1936.
823. Experimental Investigation of the Problem of Surface Roughness. By H. Schlichting. From Ingenieur-Archiv, February 1936.
824. The Photoelastic Investigation of Three-Dimensional Stress and Strain Conditions. By G. Oppel. From Forschung auf dem Gebiete des Ingenieurwesens, September–October 1936.
825. The Source of Propeller Noise. By W. Ernsthausen. From Luftfahrtforschung, December 20, 1936.
826. The Scale Effect in Towing Tests with Airplane-Float Systems. By Rudolph Schmidt. From Luftfahrtforschung, July 20, 1936.
827. Helicopter Problems. By H. G. Küssner. From Luftfahrtforschung, January 20, 1937.
828. Ground Effect—Theory and Practice. By E. Pistolesi. From Pubblicazioni della R. Scuola d'Ingegneria di Pisa, series 6, July 1935.
829. Method of Curved Models and Its Application to the Study of Curvilinear Flight of Airships. Part I. By G. A. Gourjienko. From Central Aero-Hydrodynamical Institute, Moscow, Report No. 182, 1934.
830. Method of Curved Models and Its Application to the Study of Curvilinear Flight of Airships. Part II. By G. A. Gourjienko. From Central Aero-Hydrodynamical Institute, Moscow, Report No. 182, 1934.
831. Contributions to the Theory of Incomplete Tension Bay. By E. Schapitz. From Luftfarhrtforschung, March 20, 1937.
832. The Critical Velocity of a Body Towed by a Cable from an Airplane. By C. Koning and T. P. DeHaas. From Rijks-Studiedienst voor de Luchtvaart, Amsterdam, Report A 367.
833. The Apparent Width of the Plate in Compression. By Karl Marguerre. From Luftfahrtforschung, March 20, 1937.
834. The Stability of Orthotropic Elliptic Cylinders in Pure Bending. By O. S. Heck. From Luftfahrtforschung, March 20, 1937.
835. Pressure Distribution on a Wing Section with Slotted Flap in Free Flight Tests. By Georg Kiel. From Luftfahrtforschung, February 20, 1937.
836. The Ground Effect on Lifting Propellers. By A. Betz. From Zeitschrift für angewandte Mathematik und Mechanik, April 1937.
837. Charts for Checking the Stability of Plane Systems of Rods. By K. Borkmann. From Luftfarhrtforschung, February 20, 1937.
838. The Strength of Shell Bodies—Theory and Practice. By H. Ebner. From Luftfahrtforschung, March 20, 1937.

LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

No.
205. The Hafner A.R.III Gyroplane (British). From Flight, February 18, 1937.
206. Armstrong Whitworth 27 "Ensign" Commercial Airplane (British). An All-Metal High-Wing Monoplane. From Flight, January 7, and April 1, 1937.
207. Baynes Bee Light Airplane (British). A Two-Seat High-Wing Monoplane. From The Aeroplane, March 17, 1937; and Flight, March 11, and March 18, 1937.
208. The Airspeed "Oxford" Training Airplane (British). A Two-Engine Cantilever Monoplane. From The Aeroplane, June 23, and July 28, 1937; and Flight, April 29, and July 1, 1937.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1937, as contained in the Independent Offices Appropriation Act approved March 19, 1936, was $1,158,850. A supplemental appropriation of $1,367,000 was made available in the First Deficiency Appropriation Act, fiscal year 1936, approved June 22, 1936, for the same purposes specified in the Committee's regular appropriation act for 1936, to continue available until June 30, 1937, and providing for expenditure of not to exceed $1,100,000 for the construction and equipment of an additional wind tunnel (19-foot pressure

tunnel), and not to exceed $267,000 for increasing the length of the seaplane model testing tank and for additional equipment therefor. The total amount available for general expenditure during the fiscal year 1937, therefore, was $2,525,850. The amount expended and obligated was $2,337,638, itemized as follows:

Personal services	$928,337
Supplies and materials	71,788
Communication service	3,053
Travel expenses	14,464
Transportation of things	2,742
Furnishing of electricity	36,258
Repairs and alterations	4,639
Special investigations and reports	80,744
Equipment	381,519
Structures	814,094
Expended and obligated	2,337,638
Unobligated balance	188,212
Total, general appropriation	2,525,850

The appropriation for printing and binding for 1937 was $18,700, of which $18,679 was expended.

The sum of $19,689 was received during the fiscal year 1937 as special deposits to cover the estimated cost of scientific services to be furnished private parties. The total cost of investigations completed for private parties during the fiscal year, amounting to $12,073, was deposited in the Treasury to the credit of Miscellaneous Receipts.

The amount of the regular appropriation for the fiscal year 1938 is $1,259,850, as provided in the Independent Offices Appropriation Act approved June 28, 1937. A supplemental appropriation of $453,000 was made available in the Second Deficiency Appropriation Act, fiscal year 1937, approved May 28, 1937, for the same purposes specified in the Committee's regular appropriation act for 1937, to continue available until June 30, 1938, and providing that $353,000 shall be available only for the construction and equipment of facilities and for the purchase of an airplane of the light metal private type; and providing further, that the unexpended balance of the supplemental appropriation of $1,367,000 for 1937 be continued available until June 30, 1938. That unexpended balance was $186,968. The total amount available for general expenditure during the fiscal year 1938, therefore, is $1,899,818. In addition, the amount of $21,000 was appropriated for printing and binding for the fiscal year 1938.

An allotment of $7,350 was received from the State Department for payments during the fiscal year 1937 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies, and of this amount $2,866 was paid during the fiscal year to employees of the Committee stationed in the Paris Office, leaving a balance of $4,484 turned back into the Treasury.

Of the allotment of $2,000 for participation in the Greater Texas and Pan American Exposition, which opened at Dallas, Texas, June 12, 1937, the amount of $404 was expended and obligated as at June 30, 1937.

CONCLUDING STATEMENT

The greatly extended use of aircraft for both military and civil purposes has been reflected in an increased activity on the part of progressive nations in extending their aeronautical research facilities. The demands made upon the Committee by the War, Navy, and Commerce Departments for new information are increasing in number and in difficulty with the increase in the speed and size of aircraft. The Committee fully recognizes its enlarged responsibility to make provision not only to take care of research needs arising from current problems, but also to look well into the future and to anticipate the needs that will arise as a result of the trend toward the construction of much larger landplanes and seaplanes.

The Committee is grateful to the President and to the Congress for the earnest consideration and support that have been given to its needs, and urges the continued support of this most fundamental activity of the Federal Government in connection with aeronautics.

Respectfully submitted,

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman.*

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Twenty-fourth Annual Report

of the

National Advisory Committee for Aeronautics

1938

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

TWENTY-FOURTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1938

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

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LETTER OF TRANSMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Twenty-fourth Annual Report of the Committee covering the fiscal year ended June 30, 1938.

Franklin D. Roosevelt.

The White House,
January 9, 1939.

LETTER OF SUBMITTAL

National Advisory Committee, for Aeronautics,
Washington, D. C., December 17, 1938.

Mr. President:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to submit herewith the Twenty-fourth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1938.

The past year has been one of continued progress in the technical development of both military and commercial aircraft. In the light of world events, it has become increasingly important that American aircraft, both military and commercial, have the highest possible efficiency. In the development of air strength for national defense, and in the extension of commercial trade routes in the air, a definite advantage will lie with that nation that has the most efficient aircraft.

Up to the present, the United States has led in the technical development of aircraft. The major reason for that leadership has been the farsighted support of organized scientific research in the Committee's laboratories at Langley Field, Va. American leadership is now threatened by the great expansion of research facilities in other nations. The Committee is making an earnest study of the problem presented by this condition, and is determined to make every effort to provide the scientific data necessary to keep America first in the technical development of aircraft. This will undoubtedly require material expansion in research facilities to keep pace with the accelerated research progress abroad. Upon the completion of studies now in progress, a special report on this subject will be submitted.

Respectfully submitted.

Joseph S. Ames, *Chairman.*

The President,
The White House, Washington, D. C.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems o flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members ar appointed by the President, and serve as such without compensation.

JOSEPH S. AMES, Ph. D., *Chairman*,
Baltimore, Md.
VANNEVAR BUSH, Sc. D., *Vice Chairman*,
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Chief Matériel Division, Air Corps, Wright Field, Dayto
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Dayton, Ohio.

United States Weather Bureau.

GEORGE W. LEWIS, *Director of Aeronautical Research*

JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer-in-Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

JOHN J. IDE, *Technical Assistant in Europe, Paris, France*

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AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS
AIRCRAFT STRUCTURES
AIRCRAFT ACCIDENTS
INVENTIONS AND DESIGNS

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

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Collection, classification, compilation, and dissemination scientific and technical information on aeronautics.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEETING, OCTOBER 20, 1938.

Left to right: Hon. C. M. Hester; Capt. S. M. Kraus, U. S. N.; Brig. Gen. A. W. Robins, U. S. A.; Dr. L. J. Briggs; Dr. E. P. Warner; Dr. Orville Wright; Dr. Joseph S. Ames, Chairman; Dr. C. G. Abbot; J. F. Victory, Secretary; Rear Adm. A. B. Cook, U. S. N.; Hon. E. J. Noble; Dr. Vannevar Bush; Dr. J. C. Hunsaker; Dr. G. W. Lewis, Director of Aeronautical Research. (Absent: Col. C. A. Lindbergh and Maj. Gen. H. H. Arnold, U. S. A. One vacancy: U. S. Weather Bureau.)

TWENTY-FOURTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 15, 1938.*

TO THE CONGRESS OF THE UNITED STATES:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, section 151), which established the National Advisory Committee for Aeronautics, the Committee submits herewith its Twenty-fourth Annual Report for the fiscal year 1938.

Overshadowing influence of air power.—The crisis in Europe in the fall of 1938 brought forcibly to world-wide attention the overshadowing influence of air power in international affairs. The realization that aircraft had been built in great numbers and developed to a point where they are capable of operating at high speeds over long distances with large bombing loads thrust upon the world a new concept of national defense. The imminent prospect of noncombatants being subject to indiscriminate attack by aircraft stirred the imaginations and fears of all peoples. The sudden and rather general appreciation of the potentialities of modern air power is the most significant event that has occurred in modern times in connection with strengthening the desires of peoples to avoid war.

The Committee in its annual report for 1924 discussed the increasing importance of aircraft in warfare in the light of the failure of the Limitations of Armaments Conference, held in Washington in 1921–22, to place any limitations upon the use of aircraft in warfare. The Committee at that time pointed out some of the appalling possibilities in the indiscriminate use of aircraft. These included not merely air attacks on recognized military objectives, but also attacks on civilian populations. Subsequent attempts by international conference to minimize the consequences to noncombatants have been without avail.

The Committee, therefore, in the interests of peace and security, recommends the development by the Army and Navy of adequate and effective air arms, and the early adoption of a sound program for expanding the productive capacity of the aircraft industry and for training the necessary active and reserve personnel.

Relation of aeronautical research to national defense.—The history of 1938 bears witness as to how a nation in the space of a few years, by concentrating much of its scientific research and industrial resources, on the development of air power, could gain, for the time being, a dominating position. The continued effectiveness of an air arm, however large, is dependent on constant progress in the new engineering science of aeronautics. The efficiency of an air force is in approximately direct proportion to the emphasis that is placed on scientific research in aeronautics, combined of course with engineering development, production, and training.

What has happened during the past few years that has so greatly increased the relative importance of air power in the national defense programs of nations? Of first importance are the contributions of research laboratories which have so greatly extended the speed, range, and carrying capacity of aircraft. Methods of construction also have been improved. These have included a trend toward designs of aircraft that would permit of duplicating many of the parts by the use of machinery, and thus has an approach to mass production been made. Although the designs of military aircraft of the different categories and the manufacturing methods employed in the United States have not differed widely from those in Europe, nevertheless in Europe the larger quantities manufactured have accelerated progress toward mass production methods.

Once a nation has embarked upon a program intended to develop its air strength to maximum effectiveness, the provision of adequate laboratory research facilities and the training of skilled research personnel become of fundamental importance. The major European powers at the present time are engaged on relatively large aircraft building programs which are being prosecuted under feverish pressure. Mere numbers of aircraft, however, are not in themselves sufficient for an adequate modern air force. It is of even greater importance that the aircraft be of the most effective design. The advances in aeronautical science are so rapid that assiduous attention to the subject can-

not with safety be suspended for even a brief period. Where a few years ago we were pleased with speeds of around 200 miles per hour, we now seek to attain with fully loaded service airplanes speeds of 300 and 400 miles per hour. It is not only good policy from a financial consideration, but also vital from the standpoint of national defense, that American aircraft have a performance equal or superior to that of a potential enemy. This principle necessitates serious consideration of American aeronautical research and experimental facilities.

The President and the Congress of the United States have wisely supported what has heretofore been considered a liberal program of scientic research in aeronautics. This program for years was in advance of that of other nations, and the result was that American aircraft, civil and military, have for years had superior performance, efficiency, and safety. In the commercial field, where direct evidence is available, this is proved by the large number of American-built commercial airplanes used by foreign air lines.

During the past 4 years, however, there has been increasing emphasis on aeronautical research on the part of European powers. They have greatly developed and extended their research facilities. In the rapidly advancing science of aeronautics, research problems increase in number and in difficulty with every material advance in speed, and the importance of prompt solution becomes relatively greater. The Committee's laboratories at Langley Field, Va., are working under high pressure. The requirements of the Army, the Navy, and the Civil Aeronautics Authority for the immediate solution of pressing problems are being met. But they are met at the expense of interfering with or neglecting the more fundamental scientific long-range investigations that in the end mean much to the advancement of American aeronautics. The Committee, therefore, in October 1938, created a Special Committee on Future Research Facilities. It is expected that its recommendations will be made the subject of a special report to the Congress. In the meantime, the addition to the Committee's research facilities at Langley Field of a structures research laboratory is urgently needed, as hereinafter set forth.

Relation of aeronautical research to commercial air transportation and to private flying.—Remarkable advances continue to be made in the field of commercial air transportation, and in this field the United States has for years held a recognized leadership. Although in private flying the progress has not been so rapid, the United States nevertheless has definitely excelled other nations in this field also. These gratifying conditions have been due to a combination of causes. The Civil Aeronautics Authority has provided indispensable assistance in the encouragement and regulation of civil and commercial aviation. The American aircraft industry, with its highly trained technical personnel and excellent manufacturing facilities, has been keenly alert to improve the design and quality of aircraft. The air transport lines have shown commendable initiative and efficiency in operation and have done their utmost to eliminate accidents and the causes of accidents. The high efficiency and safety of American civil and commercial aircraft are in no small measure due to the fact that the results of the scientific investigations of the Committee are generally applicable to the design of civil and commercial aircraft as well as to military aircraft.

Although popular attention during the past year has been largely focused on the significance of military aircraft developments, farsighted and determined efforts are also being made by European nations to extend their commercial and political influence by establishing and extending world trade routes of the air. Service by air lines operating under the American flag to South America and across the Pacific will soon be augmented by regular trans-Atlantic service, and it is expected that there will be inaugurated during the coming year trans-Atlantic service to the Mediterranean area. The British have established a through service by air from England to the Straits Settlements, India, and Australia, with connection to Hong Kong. One significant development in Great Britain is the policy of carrying all first-class mail by airplane throughout the Empire wherever there is air service. This practice is gradually becoming general in European nations. The British, French, and Germans have made test flights preparatory to inaugurating North Atlantic air transport services. In addition, the French are preparing to establish a service across the South Atlantic. The Dutch air transport lines now extend from Holland to Australia. Japan is rapidly expanding its air lines in eastern Asia.

In the highly competitive field of international air transportation a definite advantage will lie with that nation that has the most efficient aircraft. Continued active support of scientific laboratory research will not only pay large dividends in this field, but is absolutely essential to success.

The use of private aircraft on a much larger scale in the United States would, of course, be desirable in that it would enlarge the productive capacity of the aircraft industry, create a reservoir of pilots constituting a distinct national asset in the event of war, and provide in effect a new industry in the United States with large opportunities for employment. The technical improvement of the instruments of air transportation will be reflected in lower operating costs and in increasing availability for public service. The Committee believes that civil aeronautics will in time prove

as revolutionary in the lives of the people as the automobile. To achieve such a contribution to the progress of civilization will require not merely sound economic promotional impetus, such as the good-roads movement gave to the development of the automobile, but it will definitely require the earnest and serious support of scientific research and encouragement of experimental engineering development that will put into useful form the results of laboratory research.

The Civil Aeronautics Act of 1938.—The Civil Aeronautics Act of 1938 superseded and largely repealed the Air Commerce Act of 1926. Briefly, it established a Civil Aeronautics Authority of five members and an Administrator, for the encouragement and regulation of civil and commercial aviation, and transferred to that organization the Bureau of Air Commerce of the Department of Commerce and the Bureau of Air Mail of the Interstate Commerce Commission. The act also established an Air Safety Board for the impartial and constructive investigation of aircraft accidents. The Civil Aeronautics Authority was by that act given representation on the National Advisory Committee for Aeronautics equal to that accorded by law to the Army and the Navy. In addition, therefore, to having two members on the main Committee, the Authority also has representation on the various technical subcommittees of the National Advisory Committee for Aeronautics on the same basis as the Army and the Navy.

In connection with the broad powers given the Authority by the act to encourage the development of civil and commercial aviation, the Authority, the Administrator, and the Air Safety Board are authorized to "avail themselves of the assistance of the National Advisory Committee for Aeronautics and any research or technical agency" of the Government. Those agencies are "authorized to conduct such scientific and technical researches, investigations, and tests as may be necessary to aid the Authority, the Administrator, and the Air Safety Board in the exercise and performance of their powers and duties." To assure continuance of the proven policy of coordination of the research needs of military and civil aviation and to prevent overlapping or duplication in this field, the Civil Aeronautics Act of 1938 further provided that "Nothing contained in this act shall be construed to authorize the duplication of the laboratory research activities of any existing governmental agency."

Responsibilities of the Committee.—The functions of the Committee as prescribed by its organic act are "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution" and "to direct and conduct research and experiment in aeronautics."

To determine the present and future research needs of aviation, civil and military, the Committee has established standing technical subcommittees on aerodynamics, power plants for aircraft, aircraft materials, and aircraft structures. The subcommittees are composed primarily of specially qualified representatives of the governmental agencies concerned. The members of the subcommittees, like the members of the main Committee, serve as such without compensation.

The subcommittees recommend research programs. Most of the problems recommended for investigation are assigned to the Committee's laboratory at Langley Field, Va. Some problems are assigned to the National Bureau of Standards, when it is to the advantage of the Government to do so in order effectively to utilize existing facilities and to avoid duplication. Problems are also assigned to universities and technical schools. This policy, the Committee believes, stimulates and coordinates aeronautical research, and also has the advantage of training research personnel.

The Committee regards it as its duty to recognize in advance the trend of aeronautical development, civil and military; to anticipate the research problems that will arise; to design and provide research equipment as needed to solve the problems; to conduct the more fundamental scientific investigations in its own laboratories; and then to transmit the results directly to the governmental agencies and to those units of the aircraft industry that are most concerned.

Research facilities.—With the consistent support of the President and of the Congress, the Committee has developed at Langley Field, Va., a large and well-equipped aeronautical research laboratory, known as the Langley Memorial Aeronautical Laboratory. The rapid advance in the relatively new engineering science of aeronautics has been made possible chiefly by the design and construction of novel research equipment as needed.

At the present time the laboratories of this Committee comprise the following units: The 8-foot 500-mile-per-hour wind tunnel; the full-scale wind tunnel with a throat 60 by 30 feet; the 20-foot propeller-research-tunnel; the 5-foot variable-density wind tunnel; a 7- by 10-foot wind tunnel; a 4- by 6-foot vertical wind tunnel; a 15-foot free-spinning wind tunnel; two high-velocity jet-type wind tunnels of 11- and 24-inch throat diameters, respectively; the 2,900-foot N. A. C. A. tank; an engine-research laboratory; a flight-research laboratory; and an instrument laboratory.

In a serious effort to be prepared to solve the fundamental problems as they arise, the Committee has recently constructed three new pieces of research equipment: A 19-foot pressure wind tunnel that will permit the investigation of the characteristics of large models under conditions much more nearly paralleling those of

free flight than can be obtained in any existing wind tunnel; a refrigerated wind tunnel with a throat 7½ by 3 feet, for the investigation of problems of ice formation on aircraft; and a free-flight wind tunnel 12 feet in diameter, for studying stability and control characteristics of airplanes. The Committee has also constructed an additional shop building in which to prepare models for test in the full-scale wind tunnel and in the 19-foot pressure tunnel.

The Committee has under construction a two-dimensional flow wind tunnel, the purpose of which is to conduct investigations at higher values of Reynolds Number. The Committee has submitted estimates to modernize its 20-foot propeller-research tunnel constructed in 1927. At that time it was the largest wind tunnel in the world. It has been an exceedingly valuable piece of equipment, but the science has progressed to a point where much greater accuracy in research equipment is required. Hence the necessity for modernization. The Committee has also just completed modernizing its 7- by 10-foot wind tunnel and its 5-foot vertical wind tunnel.

Need for research on aircraft structures.—The Committee on Aircraft Structures urgently recommends that the main Committee provide at the earliest possible date a laboratory for research on aircraft structures. With the advance in size and speed of aircraft and the increasing complexity and efficiency of metal construction, the problems involved require the conduct of laboratory research on structures on an increasing scale. The main Committee, in approving the subcommittee's recommendation, came to the conclusion that this is the greatest single need for additional research equipment and that, in the interests of safety and of further progress in aeronautics, it should be provided at the earliest possible date.

Airships.—It is noted with satisfaction that approval has been given to the building of a rigid airship for naval uses as authorized by the Congress in June 1938. Although the dimensions of this airship are to be small in comparison with the largest airships heretofore built, its construction will serve to keep alive the older of the two branches of aeronautical science. From a technical standpoint it is inadvisable that airships, which have contributed so much in the past and which those familiar with the status of their development believe can contribute much more of value in the future to aeronautics, should be allowed to stand idle while other branches of aeronautics are intensively developed.

There is reason to believe that the application of recent aerodynamic knowledge, improved materials, and modern engines can be combined to produce more efficient airships. It would be a mistake to regard the airship as a craft which has reached the zenith of its development.

Building even a small airship at this time is a favorable augury that the airship branch of aeronautics, neglected in this country during the past few years, may soon resume its appropriate place in the progress of aeronautical science.

Status of Committee in time of war.—The late Maj. Gen. Oscar Westover, Chief of the Army Air Corps, shortly before his death on September 21, 1938, had, as Chairman of a Special Committee on the Relation of the National Advisory Committee for Aeronautics to National Defense in Time of War, submitted a report on this subject. The report covered the need for maintaining the efficient functioning of the Committee's organization in time of war and recommended a plan, to go into effect upon the declaration of an emergency, whereby the Committee's organization will be stabilized and may be increased as necessary to meet the needs of the Army and the Navy. The recommendations in the Westover report were approved by the main Committee. Upon their approval by the Secretaries of War and of the Navy, the plan will become effective under the provisions of the National Defense Act of 1920 as amended.

PART I

REPORTS OF TECHNICAL COMMITTEES

In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These technical committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication.

In addition to its standing committees and subcommittees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The Committee has four principal technical committees—the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, the Committee on Aircraft Materials, and the Committee on Aircraft Structures. Under these committees there are six standing subcommittees. The membership of these technical committees and subcommittees is listed in Part II.

The Committees on Aerodynamics and Power Plants for Aircraft have direct control of the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the National Bureau of Standards. Most of the research under the supervision of the Committee on Aircraft Materials is conducted by the National Bureau of Standards. A large part of the research under the cognizance of the Committee on Aircraft Structures is carried on by the National Bureau of Standards. In addition, a number of structural investigations, including in particular investigations of a theoretical nature, are conducted at the Committee's laboratory at Langley Field and at educational institutions.

The four technical committees recommend to the main Committee the investigations in their respective fields to be undertaken by educational institutions under contract with the National Advisory Committee for Aeronautics, and keep in touch with the progress of the work and the results obtained. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and aircraft structures undertaken by the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and other Government agencies are reported to these four committees.

REPORT OF COMMITTEE ON AERODYNAMICS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANDING SPEED AND SPEED RANGE

Wing flaps are now universally used on high-performance airplanes. Although previous research conducted by the Committee has established the relative merits of the usual types of flap employed, it has become apparent that more specific design data for flap application are essential. This is particularly true of flaps that are used over only part of the span. In addition, it has seemed advisable to carry further the development of the flaps that show greatest promise of improvement in airplane performance, in particular the slotted-flap and the multiple-flap arrangements. The work of the Committee on high-lift devices during the past year has been directed towards these objectives.

In the 7- by 10-foot wind tunnel, an investigation for the further development of the slotted flap mentioned in the last annual report has been carried out. By careful attention to the shape of the slot and the flap position, it has been possible to develop a maximum lift coefficient of 2.8. With reasonably high lift coefficients, it was possible to obtain drag coefficients lower than those obtained with any other type of flap tested to date. The latter flap characteristics should result in improved take-off and climb characteristics. With the flap in the retracted position, the drag of the wing at high speed is not increased by the flap installation when a small auxiliary flap is used to close the gap formed by the slot on the lower surface. The results are being prepared for publication.

An investigation has been made in the 7- by 10-foot wind tunnel of a multiple-flap arrangement in which a slotted flap was combined with a smaller plain flap, a split flap, and a second slotted flap. The results indicate that the double slotted flap is the most promising. Further work is planned with flaps of larger chord and with airfoil sections other than the

N. A. C. A. 23012, which is the only airfoil thus far used in the investigation.

Tests have also been made in the 7- by 10-foot wind tunnel of a Clark Y wing having split flaps with a gap between the flap and the lower surface of the wing. The results, given in Technical Note No. 650, show that any gap between the flap and the wing reduced the lift, the drag, and the pitching moments, but that the center-of-pressure movement and the ratio of lift to drag were little affected.

The effects of partial-span plain flaps have been investigated on both rectangular and tapered wings. The Clark Y airfoils tested were equipped with center-section and with tip-section flaps. The results (Technical Note No. 663) showed that the aerodynamic characteristics of partial-span plain flaps were, in general, similar to those of split flaps of the same span but that the lift and the drag were less for the wing with plain flaps than for the wing with split flaps of comparable size.

The "venetian-blind" type of flap has recently been receiving some attention in Europe, and tests of several different arrangements of this device have been completed in the 7- by 10-foot tunnel. The results thus far obtained indicate that the venetian-blind flap functioned similarly to a split flap when its axis was located forward of the trailing edge of the wing a distance equal to the flap chord. When the flap axis was moved back to the wing trailing edge and the flap was deflected, it acted like a multiple slotted flap and high lifts were obtained, together with low drag. The maximum lift, for the same size of flap, exceeded that of the Fowler flap, which has given the highest lifts up to the present time. Further investigation of this type of flap is contemplated.

The investigation of airfoils with flaps in the variable-density tunnel has been continued for the purpose of providing more reliable design data on the airfoil section characteristics of wing-flap combinations at the usual full-scale values of the Reynolds Number. The results of tests of ordinary and split flaps are being prepared for publication. The characteristics of the high-lift low-drag slotted flap arrangement developed in the 7- by 10-foot wind tunnel are being determined at high Reynolds Number. Preliminary results indicate a large maximum lift increment that is substantially constant over the entire scale range.

In order to provide further design data for flap application, and in particular to furnish information for structural design of the wing and the flap, pressure-distribution tests have been made in the 7- by 10-foot wind tunnel of several different wing-flap combinations. The results of such an investigation of an N. A. C. A. 23012 airfoil with an N. A. C. A. 23012 external-airfoil flap are presented in Technical Report No. 614, and a similar investigation of Clark Y and N. A. C. A. 23012 airfoils equipped with Fowler flaps is described in Technical Report No. 620. The results of pressure-distribution measurements made with a slotted flap and with a plain flap on N. A. C. A. 23012 airfoils have been published in Technical Report No. 633. Similar results from a split flap on a Clark Y–H airfoil were published in Technical Note No. 627.

The results of the investigation mentioned in the last annual report on the variation in the maximum lift coefficient obtainable with a given airplane in flight, depending upon differences in wing loading, altitude, wing-surface roughness, and the rate of change of angle of attack have been published as Technical Note No. 622. Data were obtained on the same airplane in the full-scale tunnel, and a comparison between lift coefficients measured in flight and in the full-scale tunnel is presented in Technical Report No. 618. These results show a rather close agreement between flight and tunnel measurements provided the influence of the propeller, the tail load for trim, and the effect of rate of change of angle of attack with time are taken into account.

CONTROL AND CONTROLLABILITY

As was stated in the last annual report, a critical analysis of the Committee's research on lateral-control devices which has been carried out in the past several years indicated that, for normal-flight conditions, ordinary ailerons with the gap between the aileron and the wing sealed are the most generally satisfactory. The flight investigation to verify this conclusion has since been completed and the results published in Technical Note No. 632. Additional data obtained on the same subject in conjunction with other tests on a pursuit-type airplane further substantiate the conclusion that any gap, even a very small one, is detrimental. In the case of the pursuit airplane, the maximum rate of roll obtainable was increased about 20 percent by sealing the gap of the ailerons, although the gap was only slightly more than one-eighth inch.

A method of reducing aileron operating forces suggested and analyzed in Technical Note No. 586 has been investigated in flight and the results presented in Technical Note No. 653. The method involves the use of a differential movement of the ailerons in conjunction with up-floating angle of the ailerons to obtain some degree of balance. The use of narrow-chord full-span tabs deflected downward on both ailerons was found effective in adjusting the up-floating angle to a desired value, and this in conjunction with the proper differential linkage is very effective in reducing aileron operating forces.

The results of the flight investigation of conventional and floating wing-tip ailerons on a tapered wing have been published in Technical Report No. 630.

The angular accelerations of an airplane in roll due to the application of ailerons is one of the factors representative of the control effectiveness. In order to determine what relation exists between airplane size and the angular accelerations in roll, a study is being made of data obtained over a period of several years on airplanes of various sizes. An analysis based on consideration of the time required to deflect the ailerons with a given effort by the pilot shows that the inertia of the control system is a factor of major importance as regards the accelerations obtainable.

The results of an experimental study of the forces that a pilot can exert on the control wheel of an airplane have been published in Technical Note No. 623. These data are supplementary to those previously published on the forces that can be exerted on the control stick and rudder pedal.

Lateral controls for use with full-span flaps.—Since it appears desirable to maintain as high lift coefficients as possible both for landing and taking off, the use of full-span flaps is indicated as being desirable. In this connection, the problem of satisfactory lateral control is of primary importance, and several devices for obtaining lateral control with full-span flaps have been investigated in the 7- by 10-foot wind tunnel during the past year.

A wing with a full-span slotted flap was tested with ailerons of three different types: retractable ailerons, slot-lip ailerons with the lip of the slot acting as aileron, and plain ailerons on the trailing edge of the slotted flap. The results are published in Technical Note No. 659 and indicate that, from considerations of rolling and yawing moments produced and of stick forces desired, the retractable aileron is the most satisfactory means of lateral control for use with a full-span slotted flap.

Another investigation was made to determine the control characteristics of a rectangular and a tapered N. A. C. A. 23012 wing with plain trailing-edge ailerons and full-span split flaps, the flaps retracting ahead of the ailerons. The results, published in Technical Note No. 661, show that satisfactory control could be obtained with the plain ailerons and the full-span split flap arranged to extend and retract with a hinge axis fixed ahead of the ailerons, or with the flap axis moved back to the aileron axis when the flap was deflected.

Flight with unsymmetrical power.—The failure or the intentional stopping of one engine on a multi-engine airplane results in peculiarities of control and has important effects on the performance of the airplane. In order to determine the magnitude of these effects, a large model simulating a modern twin-engine transport airplane, was investigated in the 20-foot wind tunnel. Various changes in the angle of the engines to the wing (toe-out) were tried, as well as several tail-surface arrangements. The results indicated that toeing-out of the engines or toeing-in of the rudders appear impracticable as methods of reducing the yawing moment after engine stoppage. From considerations of performance the yawed mode of flight on one engine increased the drag somewhat more than the banked mode of flight. With the particular model tested, the yaw angle required for balanced flight averaged about 5° and the bank angle required was about 2°. The results of the tests have been published in Technical Note No. 646.

MANEUVERABILITY

The investigation of the maneuverability of several Navy airplanes for the purpose of determining principally the maximum acceleration in roll and pitch to which the airplanes may be subjected has been continued. The results obtained on two airplanes have been reported to the Navy. A third airplane is now undergoing test.

An investigation has also been made of the maneuverability of a low-wing monoplane with a wing loading of 20 pounds per square foot. Previous tests of this nature, the results of which have been published, have been on airplanes with much lighter wing loadings. In general, the radii of the paths followed in recent maneuvers were considerably greater than for the machines previously tested. A report on this investigation is in preparation.

STABILITY

The extensive program of systematic research on stability problems that was formulated after a review of all the available data on the subject has continued to serve as the basis for the investigations of stability being conducted with the various facilities available to the Committee.

Research to determine the most desirable degree of stability for airplanes has been continued. One phase of the work, a mathematical study of the lateral motion induced by different types of asymmetric gusts, has been completed and the results have been published in Technical Report No. 638. The report deals with the effect of various amounts of dihedral and fin area on the motion resulting from encounters with unsymmetrical gusts of various types. The importance of proper coordination between fin area and dihedral, and in particular an unfavorable effect of relatively excessive dihedral with small fin area, is indicated.

As stability research progresses, it becomes increasingly evident that the effect of the various factors on the control and maneuverability of an airplane is of more importance than their effect on the stability itself. The requirements for stability and control generally conflict—that is, conditions that lead to greater stability also lead to greater control stiffness

and less maneuverability—and compromises must be made in design. With the increase in airplane size, the nicety of adjustment needed to produce both good stability and good control characteristics is considerably increased. Several analyses are in progress with a view to obtaining detailed information on the effect of varying the stability on the control characteristics.

The study of the relationship between the longitudinal-stability characteristics and the elevator control effectiveness is well advanced. Although no definite conclusions can be drawn as yet, it appears that the effect on the elevator control force of varying the degree of longitudinal stability through a wide range may be considerably smaller than generally supposed. A similar investigation with regard to lateral stability has revealed the fact that very little information exists on the normal flying requirements for rudder control. Most design parameters are based on the amount of control needed to prevent ground looping and to recover from spins and do not apply satisfactorily to airplanes with wheel brakes or stable landing gears, nor to the spinning categories. The investigation has therefore been extended to include a study of the functions of the rudder control.

Allied to these investigations, which primarily deal with improvement of the airplane for operation by the human pilot, is a study being made of the stability of the airplane when operated by an automatic pilot. The operation of an ideal pilot, one in which the response to a disturbance is instantaneous, has been investigated and the results prepared for publication. The effect of practical factors, such as the amount the airplane may deviate from the desired conditions before the pilot starts to respond and the time taken for the pilot to deflect the control surface, are now being considered.

With the continued study of stability problems, a better understanding of the subject is being obtained and more application of the findings is being made in actual design. As a result, there is a need for more information on the influence of the different variables in design on the stability derivatives upon which stability depends. During the past year, study was made of all available data on the derivative N_v, the change of yawing moment with change of sideslip, and the need for a systematic series of experiments on different fuselage shapes and fin arrangements is clearly indicated. A compilation of the data reviewed has been published in Technical Note No. 636.

Technical Report No. 635 has been published giving the results of an analytical investigation of the effect of the wing on the stability derivatives. The effects of taper, twist, dihedral, and aspect ratio are treated, and the data given in the report make possible the ready computation of the stability derivatives of a wing with any combination of these variables.

The stability problem is further complicated by the effect on the tail of the downwash from the wings and the wake of the wings. In the full-scale wind tunnel, downwash angles and wake characteristics have been measured in the tailplane region behind wings of various taper and aspect ratios and for flaps of various spans. From an analysis of these data, it was possible to derive a satisfactory theoretical basis for predicting downwash and wake phenomena. A report is being prepared presenting the results obtained. Also under preparation is a report containing a large number of charts covering plain and flapped wings of various types, by means of which the designer may readily compute downwash angles, wake velocities, and wake thickness in the region of the tailplane. The work is being extended to include the effects of slipstream and fuselage interference.

The investigation of wing-fuselage interference in the variable-density wind tunnel, which was extended to include the effect of adding tail surfaces to typical combinations, has been completed. A report dealing, among other things, with the wake effect and downwash angles at the tail is being prepared.

Stalling.—During the past year the considerable attention that has been given to the study of the stall has been necessitated by the undesirable stalling characteristics that exist in some airplanes of modern design.

In Technical Note No. 645 the stalling problem as related to modern low-wing monoplanes is discussed, and it is noted that basically the solution of the stalling problem consists of the elimination of rolling instability of wings. In view of the merit of low-wing monoplanes in other respects there is great need for research on this subject. For the present it seems desirable to provide means to forewarn the pilot of the approaching loss of stability when the angle of attack is being increased. The various aerodynamic effects that give warning of the stall are considered in detail.

The special wing of 5:1 taper equipped with stall-control flaps mentioned in the last annual report has been tested in flight and in the full-scale wind tunnel. The stall-control flaps are of large chord, being hinged at the 40 percent point of the wing chord. They have the effect of shifting the lift curve to the left and therefore of causing the stall to occur at a lower angle of attack. By means of these flaps it was possible to vary the span loading in any desired manner and to cause the stall to start either at the wing root or at the tip. The shape of the peak of the lift curve could be varied without materially altering the value of the maximum lift coefficient. With what appeared to be about the optimum flap setting as regards maximum lift and development of the stall, the lift curve for the complete wing was shifted about 6° to the left. The effect of this shift of the lift curve on the proper attitude of the airplane during an approach glide and landing was some-

what confusing to the pilot accustomed to the characteristics of the plain wing. Confusion would be eliminated, of course, if all landings were made with the flaps in the same position. The results of this investigation are now being prepared for publication.

The stalling characteristics of a number of airplanes ranging in size from small single-engine machines to the largest four-engine types have been studied in flight during the past year. These studies have been made by visual and photographic observations of silk tufts attached to the upper surface of the wing. Such tufts appear to be a reliable means of indicating the manner in which the stall spreads along the span, after some experience is acquired in the proper interpretation of their behavior. It has been found that the loss of lift corresponding to the stall is indicated when the tufts reverse direction or become entirely limp, whereas a fluttering or unsteadiness of the tufts is simply an indication that the stall is impending.

From observations made in these tests it appears that the type of stall which starts at the center and progresses towards the tip is the only one that produces sufficient change in the behavior of the airplane as the stall is approached to serve as a pronounced warning before rolling instability actually develops. A violent rolling motion, however, is not necessarily associated with a stall that starts at the tip. In fact, on one machine the stall started at the tip and progressed inboard so gradually and symmetrically that a gentle stall was obtained. When the stall spreads suddenly over a large portion of the wing, large rolling moments and a violent action are likely to occur, for in such cases the spread of the stall on the two wings is not likely to be symmetrical. An early stall at the wing root provides a warning of the impending loss of control but in certain cases the tail buffeting accompanying root stalling has been regarded as objectionable.

The conflicting requirements therefore leave many questions yet to be answered regarding the attainment of desirable stalling characteristics. One point not to be overlooked is that strong static longitudinal stability at high angles of attack makes it difficult to stall a machine completely; in such a case the likelihood of an inadvertent stall is much reduced.

An investigation in the variable-density wind tunnel is now in progress to determine the relative efficiency of various methods, such as twist, change of section, and change of camber, for the prevention of tip stalling. In the same wind tunnel, another investigation is in progress on wings with sweepback and sweepforward and different amounts of taper to investigate the effect of these factors on the spanwise location of the stall.

One promising method of maintaining lateral control and quasi-stability until the stall is well developed over the inner portions of the wing is the use of leading-edge slots over the outer part of the wings in front of the ailerons. In order to establish data on the best type of fixed slot for use with the N. A. C. A. 23012 airfoil, fixed slots of several forms and at several chord locations with and without slotted flaps have been investigated in the 7- by 10-foot wind tunnel. The results are being prepared for publication.

A mechanical device has been developed to provide a warning of the impending stall on airplanes in cases where the warning is not an inherent feature caused by the nature of the airflow around the wing and the tail. This N. A. C. A. stall-warning indicator operates when the angle of attack reaches the maximum safe value regardless of the air speed, so that it gives a warning independent of the wing loading. The warning indicator thus functions in proper relation to the critical airflow conditions over the wing regardless of variations in the weight carried by the machine or of variation in acceleration as in turns. Experimental installations of this device have thus far given very promising results.

SPINNING

During the past year the 15-foot free-spinning wind tunnel has been chiefly occupied in determining the spinning characteristics of scale models of ten specific airplanes. Tests for the purpose of making a direct comparison between model and full-scale spin behavior on a low-wing monoplane have been made and the results analyzed. Progress has also been made in the systematic investigation mentioned in the last annual report to determine the effects of changes in wing arrangement, in tail arrangement, and in mass distribution.

Observations made in the course of routine tests of specific designs have been definitely useful in extending the general knowledge of spinning. It has been pointed out in a published report that the effect of aileron setting on spin characteristics may be appreciable. This conclusion is substantiated by more recent results both with models and in flight. For models of modern low-wing monoplanes it has been found that recovery is frequently expedited by leaving the ailerons deflected with the spin (right aileron up in a right spin), and a study is being made of the possibility of utilizing aileron deflections to improve recovery.

General conclusions previously presented with regard to satisfactory tail design have been verified during the past year by observations made in the course of routine tests. It is of interest to note that three models having dual fin and rudder construction have been tested and all have shown very satisfactory recovery characteristics.

Experience gained in the testing of four models in the trainer and the observation-scout categories indicates that spin characteristics for the landplane type

will be less satisfactory than for the single-float seaplane.

In order to increase the available information as to the degree of reliability of the free-spinning tunnel in the prediction of full-scale characteristics for specific designs, a comparison has been made of the spinning and recovery characteristics of a low-wing monoplane tested in this tunnel and in flight. This comparison, together with the additional information obtained as a result of flight service trials, indicates that model tests give a useful, but not infallible, indication of full-scale spin behavior.

Discrepancies that have appeared between model and full-scale results indicate the need for further research on scale effect, effect of power, and effect of manner of control operation.

The investigation of the relative importance of wing arrangement, tail arrangement, and mass distribution that was mentioned in the last annual report is now about half completed. Results published thus far (Technical Notes Nos. 608, 630, and 664) have indicated that the choice of wing design may be affected by the mass distribution. Unpublished results of additional tests indicate that a forward location of the center of gravity is preferable to a rearward location regardless of wing or tail arrangement. An analysis has been started with the object of evolving a suitable airplane-spin criterion to aid designers in securing satisfactory recovery.

The results of the investigation with the spinning balance in the 5-foot vertical tunnel of the effect of stagger of rectangular biplane cellules, mentioned last year, have been published as Technical Note No. 625. An investigation of the effects of airfoil section on the spinning characteristics of rectangular monoplane wings with rounded tips has been described in Technical Note No. 633. The airfoil sections investigated were the N. A. C. A. 0009, 23018, and 6718, and the data for the Clark Y wing presented in Technical Note No. 612 were included for comparison. These data can be used in studying the steady-spinning characteristics of particular airplanes, and the results of the analysis given in these papers can be used to predict whether changing the wing loading or the weight distribution of an airplane will be beneficial or detrimental to its steady-spinning characteristics. For comparable cases, these results and the results obtained on models in the free-spinning wind tunnel have shown the same general tendencies.

In connection with the determination of spinning characteristics of various models in the spin tunnel, there has been a continued demand for the Committee to determine experimentally the moments of inertia of full-size airplanes. These measurements are carried out by means of the swinging gear, which has been in use for several years.

TAKE-OFF

The investigation discussed in the last annual report of the transition period in take-off between the end of the ground run and the beginning of the climb has since been described in Technical Report No. 626. Additional data concerning the ground run and the transition to climbing flight in take-off have been obtained in conjunction with an investigation of the effect of two types of full-span flap on take-off, one being a high-drag type represented by the Zap flap and the other being a low-drag type represented by the external-airfoil flap. These tests are an extension of an earlier investigation made with a machine of such low power that the results were not representative of conditions ordinarily encountered in transport or military operation. The data obtained in these tests are now being analyzed.

As has been pointed out, the characteristics of the propeller have a pronounced influence on the take-off. An extensive investigation of full-scale propellers has been conducted in the 20-foot wind tunnel to provide information on modern propellers. This constitutes a considerable extension of the Committee's early investigations to provide propeller design data and covers principally the changes in design necessitated by higher engine power and airplane speed. These trends call for propellers of higher pitch, more blades, and changes in blade form. The investigation has now been completed, and is discussed more completely in a later part of this report. Of six reports published during the year on the results of the investigation, three (Technical Reports Nos. 639, 640, and 643) contain data directly applicable to the take-off problem.

LANDING

In connection with the general study of landing characteristics of airplanes, an investigation of ground effect has been carried out with a glider of aspect ratio 7.5 towed by an automobile at various heights above the ground up to about 50 feet. The data obtained in this investigation, which was made both with a plain wing and with a wing fitted with a split flap, are now being analyzed. For the plain wing the slope of the lift curve was increased about 30 percent with the glider 5 feet above the ground, as compared with the slope when it is 50 feet above the ground. The drag at a lift coefficient of 1.0 was about 15 percent less when the glider was close to the ground. The maximum lift coefficient of the plain wing was much higher (about 25 percent) in actual landings than in simulated landings made at considerable altitude.

Landing loads.—As stated in the last annual report, the Committee is undertaking the accumulation of statistical information on the loads experienced by the landing gear. This investigation has been continued during the past year and tests have been made with seven additional airplanes covering the complete range

of sizes of airplanes now in operation. A tricycle type of landing gear as well as conventional types was included. The attitude and the vertical velocities of the airplanes immediately prior to contact, in addition to the linear and angular accelerations, were determined.

Tricycle-type landing gear.—There has been a very definite growth of interest among American manufacturers in the use of tricycle-type landing gears during the past year, and the indications are that many new models of transport and private-owner machines, in particular, will be equipped with this type of gear. During the past year the Committee has continued the investigation of the shimmy of castering wheels and also its study of the landing loads experienced with the tricycle-type landing gear.

The analytical study of the shimmy of castering wheels that was mentioned in the last annual report has been completed and the results are being prepared for publication. The report will give methods for estimating the spindle damping that is necessary to avoid shimmy.

An airplane fitted with a nose wheel was used in tests of the effect of caster length on the tendency of the wheel to shimmy for comparison with tests made on a small-size model. A conclusion based on model tests that the provision of lateral freedom of the wheel would eliminate shimmy was not confirmed by the tests of the full-size machine.

Apparatus has been constructed for conducting tests with various types of airplane wheels in order to determine the friction required to prevent shimmy. By means of this apparatus the weight, the caster length, and the spindle angle can be varied as desired in order to cover a wide range of conditions. Tires ranging in characteristics from those of the extra-low-pressure type to those of a solid tire are being investigated.

As noted previously, landing-load tests have been made with one airplane having a tricycle type of landing-gear arrangement. Plans are also under way for tests of another machine having this type of landing gear. In both of these cases, particular attention is being paid to the determination of the loads on the nose wheel.

It has been found advantageous to employ actual airplanes or relatively large models of large airplanes in the Committee's full-scale tunnel in order to study various changes that may be made to improve service airplanes. Difficulties may sometimes be located and changes studied by means of wake surveys. From the test results, it was found that, for the high-speed condition, the drag of retracted landing gears accounted for from 2 to 9 percent of the drag of the airplanes. It was shown that this drag could be greatly reduced by improving the fairing of the landing gear in the retracted condition. In one case it was found possible to reduce the drag of an airplane by 14 percent by modifying the engine cowling. Other reductions in drag were found to be possible by redesigning exhaust stacks. The profile drag of service wings was measured by momentum surveys in the wakes of the respective wings, and by a comparison of this information with data obtained on smooth wings of the same sections it was found that the surface roughness, consisting of protruding rivet heads, lap joints, etc., accounted for from 10 to 35 percent of the wing profile drag. These investigations indicated the possibility of increasing the speeds of several airplanes by varying amounts of from 15 to 23 miles per hour and they demonstrate the advantage of being able to put the actual airplane in the tunnel as compared with the use of models.

AIRFOILS

Section characteristics.—Comparisons of airfoil data from the variable-density wind tunnel with results of other large-scale tests, including data now becoming available from the N. A. C. A. full-scale wind tunnel, other large wind tunnels, and the British compressed-air tunnel, have been of decided assistance to the program of airfoil investigation. These comparative data have aided in formulating turbulance corrections for wind-tunnel test data, such as those employing the concept of an "effective Reynolds Number," but such corrections cannot be considered ultimately satisfactory. The basic program of airfoil investigation has therefore been primarily concerned during the year with the development of better methods of conducting tests, and of methods for the derivation of new airfoil forms in the light of modern boundary-layer theory.

Investigations of airfoil section in the variable-density wind tunnel of the type that led to the development of the commonly used sections of the N. A. C. A. 230 series have been continued. Profile-drag coefficients determined from tests in the variable-density wind tunnel have, however, tended to appear high as compared with results from the N. A. C. A. full-scale tunnel and from foreign sources. The results from the variable-density wind tunnel have also indicated larger rates of increase of drag with airfoil thickness than have those from other sources. These discrepancies have been considered and corrections for turbulence and tip effects have been applied which tended to reduce them.

Further investigations of this subject have been made, including tests of three symmetrical airfoils in the full-scale wind tunnel (Technical Report No. 637). The results of these tests confirmed the existence of discrepancies in addition to those arising from differences in turbulence between airfoil data from the full-scale and variable-density wind tunnels. The results from the full-scale tunnel indicated the presence of support-

strut-interference effects in the variable-density tunnel causing the measured drag to be too large, the drag increments due to support interference being greater for thick airfoils than for thin ones.

A subsequent investigation in the variable-density wind tunnel confirmed the presence of marked drag increments due to support-strut interference, the increment increasing with airfoil thickness. The application of corrections for this factor to the data obtained from the variable-density wind tunnel substantially removes the above-mentioned discrepancies. The most important result is that the smaller increase of drag with thickness affects the choice of optimum airfoil sections for airplane wings. Reports are being prepared presenting the results of these investigations.

A preliminary investigation has been made in the variable-density wind tunnel to study the stalling processes for four typical airfoil sections over the critical range of Reynolds Number. The flow was studied by means of tufts and a mixture of lampblack and oil spread on the surface and the observations were correlated with force measurements. The results tend to substantiate the analysis of stalling in Technical Report No. 586.

Transition on airfoils.—Because the aerodynamic characteristics of airfoils in relation both to maximum lift and minimum drag depend markedly on the transition from laminar to turbulent flow in the boundary layer, knowledge of the region in which transition occurs is a matter of considerable practical importance. The maximum possible extent of the laminar boundary layer is therefore of particular interest. In one respect, this extent is limited by the position of the laminer separation point. Of the various methods available for calculating this position, the method presented in Technical Report No. 504 seems to be the most reliable. This method, however, has the disadvantage that the computations are usually cumbersome and lengthy.

A method of rapidly estimating the position of the laminar separation point from the given pressure distribution along a body has been found; the method is applicable to a fairly wide variety of cases. The laminar separation point was found by the method of Technical Report No. 504 for a particular series of velocity distributions along a flat plate. They consisted of a region of uniform velocity followed by a region of uniformly decreasing velocity. It was found that such a velocity distribution can frequently be assumed equivalent to the actual velocity distribution along a body in so far as the effects on laminar separation are concerned. The agreement between the position of the separation point calculated according to the present method and that found from more elaborate calculations is very good. This rapid method of estimating the position of the laminar separation point is soon to be presented in a Technical Note and should find frequent use in connection with estimates of possible position of the transition point and the attendant effects in various practical cases.

As another part of the Committee's general program for studying transition, measurements have been made on the N. A. C. A. 0009, 0012, and 0018 airfoils in the full-scale wind tunnel. The smoothly polished airfoils were of 6-foot chord and were tested over a range of Reynolds Number from approximately 1,500,000 to 5,000,000. Measurements were made both by means of total-head tubes in the boundary layer, so as to obtain the boundary-layer profiles, and by means of a hot wire at the airfoil surface. The results of this investigation, which show a variation of the transition point as a function of airfoil thickness, Reynolds Number, and lift coefficient, are published in Technical Report No. 637.

Another investigation of boundary-layer conditions, especially dealing with the location of the transition from laminar to turbulent flow, is in progress in the 8-foot high-speed tunnel. Here, by the use of two airfoils of different size and with the possible speed range and the low-turbulence air stream of this tunnel, the combined effects of scale and compressibility in relation to transition may be investigated.

A determination of the profile drag and the transition point in the boundary layer on a very smooth wing section in flight has been carried out at a Reynolds Number of about 4,500,000 with one airplane. These data are of value for comparison with data from the full-scale tunnel to evaluate any residual effects of the relatively small turbulence of the full-scale wind tunnel on the characteristics of aerodynamically smooth bodies.

In order to extend the range of profile-drag measurements at low turbulence to high Reynolds Numbers, flight tests were also made on an airplane of such size and speed that a Reynolds Number of 15,000,000, based on the chord length, was obtained. A portion of the wing of this airplane was made very smooth by the application of a combination of rubber and metal coatings. A paper on the results of these measurements is in preparation.

Roughness.—A continuation of the investigation of wing-surface conditions is being carried out in the 8-foot high-speed tunnel. The effect on wing drag of various construction conditions occurring in practice, such as butt joints with gaps, butt joints that are not flush, faired lap joints, spot welds, rib stitching, etc., have been determined. The investigation concludes with a systematic study of irregularities in wing profile.

Compressibility effects.—The analysis of a large amount of data obtained from investigations of the nature of the compressibility burble has been com-

pleted and prepared for publication as a Technical Report. An investigation of the variation of the drag coefficients of cylinders of simple shape for a wide range of Reynolds Number and speed that has been conducted as time permitted has been completed and the results published in Technical Report No. 619.

Work now in progress in the 24-inch high-speed wind tunnel consists of an extension of the earlier wing development carried out in the 11-inch high-speed wind tunnel. The energy loss involved in the compressibility burble tends to act as a limiting condition for the speeds of airplanes of current and typical design either through propeller restrictions or ultimately through restrictions on other parts of the airplanes. Although knowledge of the phenomenon has increased markedly through experimental work over the last four years, the phenomenon is still one of the most important flow problems in current aerodynamics. Further study of the mechanics of this flow phenomenon is being made.

Wing characteristics.—The calculation of the characteristics of 22 tapered wings of varying aspect ratios and taper ratios has been completed and shows reasonably good agreement with experimentally determined values of pitching moment, aerodynamic-center position, lift-curve slope, and drag variation. The results have been published as Technical Report No. 627.

The same aerodynamic characteristics have also been calculated for a few wings with partial-span flaps. Fair agreement with test results was obtained in most cases. The results are to be published, together with information on the theoretical factors involved in the determination of characteristics of tapered wings with partial-span flaps.

As a part of a recent study of the stalling of wings, a series of tests is in progress in which photographs are obtained of the action of tufts on wings with sweepback and sweepforward and different amounts of taper, to investigate the effect of sweep on the spanwise location of stalling. Another investigation using wings of different taper is being made to find the relative efficiency of various methods of preventing tip stalling.

AERODYNAMIC INTERFERENCE

The investigations conducted in the variable-density wind tunnel of the effects of split flaps and special junctures on the aerodynamic interference between wing and fuselage have been published as Technical Notes Nos. 640, 641, and 642. The investigation of the effects of adding tail surfaces has been completed and a report presenting the results is being prepared. Of interest are the small size of the increments to the drag caused by the tail surfaces, as well as the agreement between theoretical considerations and experimental determination of the wake effects and the downwash angle at the tail. The induced interference of the fuselage on the downwash angle, moreover, was negligible at low angles of attack and small at high angles. Asymmetrical combinations, however, showed initial deviations in the flow direction at the tail at low lift coefficients.

An experimental investigation of the mutual effects of interference and compressibility phenomena is in progress in the 8-foot high-speed wind tunnel. Results have been obtained for several arrangements of radial-engine nacelles on a wing to determine the effect of present-day nacelle arrangements at high speeds, but conclusions cannot as yet be drawn.

DRAG AND COOLING

Engine location.—One of the most obvious possibilities for substantial improvement in aerodynamic efficiency lies in the reduction of the drag of the engine installation and the cooling system. Tests were conducted in the full-scale wind tunnel on a representative 4-engine model to evaluate the drag of a typical liquid-cooled power plant. These tests showed that the engine nacelles increased the drag of the airplane about 8 percent and the cooling system (prestone and oil radiators) accounted for over 15 percent more. Further tests were made simulating the arrangement of engines placed within the wing with extension shafts to either tractor or pusher propellers. The extension-shaft drive practically eliminated the nacelle drag.

For the development of an efficient cooling system for engines or radiators located in the wing, investigations have been conducted in the 7- by 10-foot atmospheric wind tunnel and in the full-scale wind tunnel. The general principle of the arrangements investigated is that of low-velocity cooling with the cooling element placed at the largest section of a duct. Arrangements already tested have shown large reductions in drag under all flight conditions.

In the 7- by 10-foot wind tunnel the tests were made to simulate a radiator or engines enclosed entirely within the wing and cooled by air led through ducts from the wing surface. The results obtained on a wing model with full-span ducts and radiators have been reported in preliminary form. For certain locations of the duct inlet and outlet the total power required to cool such an installation is only the power required to force the air through the radiator. Thus the cooling power may be of the order of 2 or 3 percent of the engine power as compared with the 10 to 15 percent now required on radiator installations. The results of these tests will be published as a Technical Report.

Radiator study.—A comprehensive study of aircraft-radiator design and installation has been made. The choice of radiator dimensions is made on the basis of cooling efficiency, which is the ratio of heat dissipated to power required for cooling. The power required for

cooling is made up of three factors: (1) power to force the cooling air through the radiator; (2) power to carry the weight of the radiator; (3) power to overcome form drag. The importance of these three power expenditures varies with installation, airplane performance, pressure drop, coolant, and altitude. The heat dissipation varies with mass flow of air through the radiator, the length-diameter ratio of the radiator tubes, and the temperature difference between air and coolant.

This study on radiators comprises one phase of the heat-transfer problem. The problem of intercooler design and installation is also under investigation at the present time. The radiator problem is concerned with the case where nearly all the thermal resistance is at one surface, while the intercooler problem is concerned with a case of two surfaces having relatively the same thermal resistance.

Cowling research.—The information from tests on the propeller-cowling-nacelle combinations presented in Reports Nos. 592, 593, and 596 and Technical Note No. 620 has been summarized for design purposes in a report entitled "Design of N. A. C. A. Cowlings for Radial Air-Cooled Engines." The main emphasis of this report is placed on the method of obtaining the dimensions of the cowling. A practical method of designing cowlings and some examples are presented.

A study of the factors affecting the pressure available for ground cooling in front of air-cooled engine cowlings has been made. Most of the work was conducted on a model of about one-third full scale. A number of isolated tests on four full-scale airplanes were made as a basis of comparison of model and full-scale results. The available pressure in front of the cowling increases rapidly with the diameter of the opening of the cowling up to 30 or 40 percent of the propeller radius. The cowling should be located as close to the propeller as practicable. Disks located in the front of the nose of the cowling greatly increased the average pressure in front of the engine. It is important that the plane of the disk be even with the nose of the cowling. The size of the disk should be such that the area of the front opening is optimum for the total conductivity used. A report is being prepared on this investigation.

Investigation of the nose-slot cowling has been continued on a full-size airplane. The ground cooling of the engine was improved by proper cowling design and a $\triangle P/q$ of 1.6 was obtained in full-throttle climb. In order to expedite the study of the problem, it was decided to continue the work in the 20-foot wind tunnel. These tests are now in progress and should supply sufficient information to determine the best design of nose-slot cowling for any given design condition. In connection with the wind-tunnel investigation the cost in drag of the bluntness of the radial-engine cowling is being investigated and means to reduce this drag are being studied.

Scoops and vents.—An investigation of air-inlet and outlet openings suitable for cooling and ventilating systems, carburetor intake, and engine exhaust has been undertaken. A momentum theory of the generalized induced-flow system was derived to serve as a basis for the explanation and the correlation of experimental results, particularly the results of wind-tunnel tests of separate openings. This theory provides a simple method of determining roughly the effects of the internal induced-flow system. It suggests the optimum locations for inlet openings, the optimum angle and velocity of the jet for outlet openings, and the cost of departures from those optimums; and it illustrates the close relationship of the several types of induced-flow system. An extensive experimental investigation was made in the N. A. C. A. 5-foot vertical wind tunnel of a large number of openings in a flat plate and of a few in an airfoil, all tests covering the complete range of self-induced flow and the practically useful range of blower-induced flow. The experimental results verified the trends indicated by the theory wherever comparisons were practicable, and the quantitative agreement between theory and experiment is considered satisfactory for the most efficient opening shapes and locations. The test conditions and the models were systematically varied so that the results indicate the effects of wind velocity; size, shape, and location of openings; length and angle of ducts; and some of the interference between an opening and a body, and between inlet and outlet openings in the same body.

The location of the carburetor intake has been separately investigated in the propeller-research wind tunnel. A ramming effect due to the dynamic pressure of the air stream may be desirable. Tests of several intakes were made with the radial engine cowling used in the propeller investigation. The best results were obtained with a well-rounded entrance located near the leading edge of the cowling on the outside. The propeller also contributed to the ramming effect when the scoop was so located. The results of the tests are published in Technical Note No. 631.

PROPELLERS

An extensive investigation of full-scale propellers started last year has been completed. A number of propellers with various airfoil sections, different numbers of blades, and several plan forms and pitch distributions were tested in conjunction with two bodies representing radial-engine and liquid-cooled-engine nacelles. A range of positive blade-angle settings up to 45° at the 75-percent radius was covered, as well as some negative settings.

Many of the conclusions were presented in the last annual report and these have not been altered by the tests made this year. Because of the large amount of data, it was found advisable to prepare a series of re-

ports each devoted to a particular phase of the study. Eight reports have been prepared, six of which have been published as Technical Reports Nos. 639 to 644.

With regard to compressibility, Technical Report No. 639 indicates that at normal pitch settings losses in efficiency become evident at tip speeds of from 0.5 to 0.7, the velocity of sound for the take-off and climbing conditions of flight. The loss increases rapidly with speed and amounts to more than 20 percent of the thrust power in some instances for tip speeds of 0.8 the velocity of sound.

The loss for the take-off condition increased with blade-angle setting up to about 20°, diminishing at higher values. For the climbing condition the loss increased up to a 25° setting. The loss in efficiency for controllable propellers is partly regained by the lower blade angles necessitated by the higher power coefficients developed at the higher tip speeds. On the other hand, the loss for fixed-pitch propellers is increased by the loss in speed and power caused by the higher power coefficient. The complex effects of compressibility were subject to detailed study and an appendix to the report develops methods for making corrections in practical problems.

Technical Report No. 640 discusses the effect of the number of blades, indicating that, for the same solidity (total blade width), the efficiency is increased by increasing the number of blades. Even when the solidity was doubled by changing a 2-blade to a 4-blade propeller, the loss in efficiency was only 2 percent. At the same time the take-off efficiency was improved.

The negative thrust condition occurs in diving at high speeds and idling at low speeds. Technical Report No. 641 gives data and examples for calculating the magnitude of the thrust developed under these conditions of operation.

When a spinner is added to the propeller of a radial air-cooled engine, the principal effect is an improvement in the flow through the engine cowl. With some installations of liquid-cooled engines, however, the spinner covers up the propeller hub and the round blade shanks. The propulsive efficiency was increased 6 percent in one case. Blade shanks of good airfoil shape were found superior to the round shanks with both types of nacelles. (See Technical Report No. 642.)

Technical Report No. 643, relating to plan forms, indicates that some improvement may be expected by having the blade width in the inner half of the blade greater than is the usual practice. The take-off efficiency, however, is reduced.

A more accurate method of measuring propeller deflections was developed and is described in Technical Report No. 644. Measurements gave much smaller deflections than the methods formerly used. Torsional deflections of only $\frac{1}{10}°$ at the 0.70 radius were noted. The bending deflection was also small.

The results of the study of airfoil sections indicate that no section thus far tried is the best for all conditions of operation. Highest maximum efficiencies were obtained with airfoils of low camber such as the N. A. C. A. 2400–34 and the Clark Y. For both controllable and fixed-pitch propellers of the same diameter, the R. A. F. 6 was best in the take-off range. Blade sections for controllable propellers, not limited in diameter, should be selected mainly on a basis of drag.

There has been a feeling that propellers designed with low basic pitches and then set to high angles suffered because of the large change in pitch with radius. Tests in which a propeller was twisted to give a uniform pitch when set at 35° gave a lower maximum efficiency than a normal propeller set to this angle. A gain in take-off efficiency at low angle settings was noted.

Tests in wind tunnels do not yield data on the static thrust of propellers because the propeller creates an appreciable velocity through the tunnel. The static thrust is useful in certain aspects of performance computation and, in order to obtain this information for direct comparison with values obtained in the tunnel, the wind-tunnel set-up has been installed on an outdoor rig. A series of tests on propellers previously tested in the tunnel has been completed and the data are now being analyzed.

THEORETICAL AERODYNAMICS

Normal force and pressure distribution over airfoils.— For the calculation of air loads along the wing chord in airplane design it has been customary for the designer to employ an arbitrary normal-force distribution that agrees only very roughly in form to the distribution which would result from experimental observations. This method, while admittedly crude, is rapidly and easily employed. Consequently, it is frequently used in preference to the theoretical method of Technical Report No. 411. Moreover, the theoretical method itself predicts a distribution which is in none too good agreement with experiment. A modification of this theoretical method (Technical Report No. 563) that yields results in good agreement with experiment has been advanced but this modified theory is even more laborious to employ.

A method for the prediction of the chordwise normal-force distribution in which attempt is made to retain the simplicity of the arbitrary method and the exactness of the modified theoretical method has recently been developed by the Committee. This method is applicable to ordinary airfoils (Technical Report No. 631) and to airfoils with plain, split, and serially hinged trailing-edge flaps (Technical Report No. 634) but

does not give separately the pressure acting on the upper and lower surfaces of the airfoils. At present the Committee is continuing work on a method of determining these pressures. This method as evolved is easily and rapidly applied and to date appears to be accurate enough for design purposes.

Theory of unsteady flow.—A theoretical study has been made of transient, or nonstationary flows, about airfoils and the results presented in Technical Report No. 629. It has been shown that the two-dimensional problem can be made to depend on two significant functions: one introduced by Wagner and the other introduced by Theodorsen. These functions are Laplacian transforms of each other. The growth of lift on an airfoil in two dimensions becomes analogous to the growth of electric current in a circuit. The function of Wagner then corresponds to the indicial current admittance and the function of Theodorsen to the alternating current complex admittance. As in electric-circuit theory the current due to any applied voltage can be built up by superposition, so in the case of the airfoil the lift due to any "applied vertical velocity" can be obtained by superposition. Thus, many practical general problems concerning the transient behavior of lift under changing flow conditions can be handled.

In the analysis of some of the results recently obtained in the wind tunnels, more particularly in the gust tunnel, application has been made of the fundamental theory of unsteady flow. The existing theory, however, considers only the case of a wing of infinite span and consequently does not entirely fit the conditions of the tunnel tests. A study has therefore been started to extend the theory to cover the three-dimensional case of the wing with finite span. Although a rigorous treatment has not yet been evolved, a practical extension to the two-dimensional theory has been worked out. A Technical Note presenting the present development is in preparation. A second note presenting an operational mathematical method of applying the unsteady-lift theory to specific dynamical problems is also being prepared.

Compressible flow.—A theoretical investigation of the effects of compressibility on the flow past an obstacle was made and the results applied to the cases of symmetrical Joukowsky profiles and elliptical profiles. The results were obtained in a closed form and are exact in so far as the second approximation to the compressible flow is concerned, the first approximation being the result for the corresponding incompressible potential flow. For the case of the symmetrical Joukowsky profile (Technical Report. No. 621) the angle of attack was taken to be arbitrary and the circulation chosen according to the Kutta condition. Formulas were developed for the velocity increments at the surface of the airfoil due to compressibility. In addition, formulas for the lift and the moment were given for thin profiles at small angles of attack. For the case of the elliptical profile, since the angle of attack was taken to be zero, expressions for the velocity distribution at the surface only were obtained (Technical Report No. 624). At the present time an investigation is in progress concerning the moment on an elliptic cylinder immersed in a two-dimensional subsonic compressible flow.

WIND-TUNNEL CORRECTIONS

Reasonably satisfactory theoretical methods have been available for years for correcting the results from open and closed wind tunnels of different commonly used sections, such as circular and square, in which the span of the airfoil or airplane model does not exceed about 75 percent of the tunnel width or diameter. It is still necessary to determine experimentally the corrections to allow for individual shapes of throat, as in the case of the oval throat of the full-scale wind tunnel, or for the cases in which the airfoil spans the jet completely, as in the cases of the Committee's high-speed wind tunnels.

The full-scale wind tunnel.—Comparisons between test data obtained in flight and in the full-scale wind tunnel have shown that the results obtained in the tunnel closely approximate free-flight conditions. The results of a comparison of the maximum lift coefficients obtained with a Fairchild 22 airplane in flight and in the tunnel, mentioned in the last annual report, have now been published as Technical Report No. 618.

As a part of a general research program which has as its objective the improvement of the correlation of data obtained in the various wind tunnels of the Committee, the aerodynamic characteristics of three 6- by 36-foot airfoils of symmetrical section have been determined in the full-scale wind tunnel. The thickness ratios of these airfoils ranged from 9 to 18 percent to cover a normal range of wing thickness. A comparison of these data with results obtained with the same airfoil sections in other wind tunnels will result in improving the precision with which wind-tunnel data may be applied to flight conditions. The results of this investigation are presented in Technical Report No. 647.

The 7- by 10-foot and the 4- by 6-foot wind tunnels.—An investigation has been started in the 7- by 10-foot wind tunnel, in which the airfoils span the rectangular throat, to determine the correction necessary to reduce airfoil data obtained in that tunnel to true airfoil section characteristics. Thus far, the investigation has yielded a satisfactory correction to the lift that is in good agreement with the theory. The corrections for the drag and the pitching moment are not yet considered entirely satisfactory, and further tests are contemplated.

Until recently the 5-foot diameter vertical tunnel has been used principally for investigations relating to the

spinning problem. This tunnel has now been changed to have a rectangular 4- by 6-foot closed throat and is to be used chiefly for studies involving two-dimensional flow. The modification of this tunnel now makes available a piece of equipment that should be fairly well adapted to this type of work and also well adapted to general aerodynamic research at moderate values of the Reynolds Number.

The 11-inch, the 24-inch, and the 8-foot high-speed wind tunnels.—Preparatory to an investigation of special airfoils suitable for high-speed applications, an extensive investigation of tunnel-wall effects has been made for the 11-inch, the 24-inch, and the 8-foot high-speed wind tunnels. Inasmuch as these tunnels are all of circular throat and the airfoils are mounted similarly in all, it was possible by a comparison of the results from airfoils of corresponding chord from the three tunnels to determine the correction for each. Preliminary work was conducted in the 11-inch and the 24-inch wind tunnels. Later, tests identical in nature were made in the 24-inch and the 8-foot wind tunnels to check the the preliminary work and finally to evaluate the wall effect and the end-leakage corrections for the drag and the lift-curve slope.

EFFECTS OF ICE FORMATION AND ITS PREVENTION

The icing of aircraft is still one of the most serious problems confronting airplane operators. An investigation was made during the past year in the full-scale wind tunnel to determine what effect ice formation has on the aerodynamic characteristics of a wing. A formation simulating one depicted in photographs forwarded by one of the air-line companies was built up on an N. A. C. A. 23012 airfoil and tested. It was found that the maximum lift coefficient was reduced from 1.32 to 0.80 by the formation and the profile-drag coefficient was increased by 90 percent. It can be seen that the increased stalling speed resulting from such a formation could be very dangerous, particularly if the pilot had to rely upon his air-speed indicator to warn him of the approaching stall.

In order to obtain a clear statement of the various aspects of the icing problem, a questionnaire was submitted to air-line operators during the past year requesting them to outline the difficulties experienced in flight and to suggest a line of research. The replies obtained from this questionnaire have served as the basis for the preparation of a comprehensive program of research. The carrying out of this program will be facilitated by the new refrigerated tunnel, which has been recently added to the Committee's equipment. This tunnel makes possible the testing of models having a chord up to 6 feet.

Preliminary tests have been carried out in this tunnel to study the use of exhaust heat as a means of preventing ice formation on the leading edge of a wing. The possibility of using steam generated by the exhaust heat to prevent ice formation is being investigated on an airplane in flight. In these tests, the exhaust from one cylinder of a 9-cylinder engine is used to generate steam that is conducted to a condenser covering a portion of the leading edge of the wing. From the results of the tests both in the wind tunnel and in flight, it appears that, although there is plenty of heat available in the exhaust, merely heating the leading edge of the wing is insufficient. It is now planned to extend the study to investigate means of distributing heat over the entire wing chord.

Additional flight tests have been made to test the usefulness of preparations that decrease the adhesion of ice to the wing. Preparations containing soluble materials have thus far been found to be practically worthless. Other tests conducted with a mercury-amalgamated surface showed that, even though the adhesion of ice to the wing was reduced to a very small amount, the ice would continue to form in practically the same manner as on the untreated surface.

ROTATING-WING AIRCRAFT

In the hope of developing an improved method of direct control for rotating-wing aircraft, research during the past year has been restricted to a theoretical study of rotor control systems. The effect of periodically feathering the blades of an articulated rotor has been analyzed in detail and the aerodynamic identity of the Hafner and Cierva control systems has been mathematically demonstrated. As yet the study has not been extended to cover feathering control of rigid rotors but it is hoped that this can be done in the near future.

A study of the torque equilibrium in the autogiro rotor has been completed and the results published in Technical Report No. 623. This study simplifies and improves the previous method of calculating the inflow velocity required to maintain autorotation in a given rotor. Correct estimation of the inflow is particularly important because all rotor characteristics depend directly on inflow velocity.

MISCELLANEOUS TESTS OF MODELS AND AIRPLANES

In accordance with requests of the Army and Navy and in keeping with the policy of the Committee, a large number of complete airplane models have been investigated in the full-scale, the 20-foot, and the 7- by 10-foot wind tunnels. Most of the models have been tested for the military services but some have been tested for manufacturers at their expense.

In order to determine means for eliminating errors due to variations of wind velocity with height, a series of flight performance tests has been made with airplanes under conditions such that the effect of the

gradients could be determined. The results of these tests, which are now being analyzed, indicate that such gradients as are experienced in ordinary weather may influence the rate of climb by as much as 10 percent.

NATIONAL BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Wind-tunnel turbulence.—The most useful method of describing the statistical properties of wind-tunnel turbulence appears to be that in terms of intensity and scale, corresponding to the description of the molecular motion of a gas by average molecular velocity and mean free path. Extensive measurements of scale and intensity and of their aerodynamic effects on the drag of spheres were published last year in Technical Report No. 581.

It is also possible to give a somewhat more detailed picture by considering the fact that eddies of different size are present and investigating the distribution of intensity with size. The procedure is analogous to the classical treatment of light waves. By inserting electrical filters in the amplifier circuit of the usual hot-wire equipment, it is possible to determine the "spectrum" of turbulence. The spectral distribution curve gives the fraction of the total energy of the turbulence arising from frequencies in a narrow region as a function of the mean frequency of the region.

Some studies of this type have been made during the past year. In the interim G. I. Taylor has shown that the spectrum curve is the Fourier transform of the correlation curve used in determining the longitudinal scale of the turbulence, and one may readily be computed from the other. Our measurements confirm this result, and the forms of the curves suggest that wind-tunnel turbulence is a generalized chance phenomena.

The study of the change in the spectrum as the turbulence decays shows that the energy in various frequency bands does not decay independently or according to any simple law but that there is a continual transfer from low frequencies to high frequencies.

The results of these studies were presented at the Fifth International Congress for Applied Mechanics and will be published in the proceedings of the Congress.

Effect of turbulence on boundary layers.—In the annual report last year a rather extensive account was given of the work then in progress on the study of the speed distribution in the boundary layer of an elliptic cylinder at tunnel speeds high enough to produce transition from laminar to eddying flow and for intensities of turbulence of 0.85 and 4.0 percent. A description was given of a simple device consisting of a hot wire on a sliding band, for quickly locating the transition. With this device a survey was made of the effect of intensity and scale of turbulence on the location of the transition zone. It was found that the distance of the transition zone from the nose was a function of the product of the intensity of the turbulence by the fifth root of the ratio of a characteristic dimension of the cylinder to the scale of the turbulence, corresponding to the theoretical relation suggested by G. I. Taylor. A report on the work is in process of publication as a Technical Report.

Investigation of boundary layer by diffusion of heat.—Studies of turbulence within a thick boundary layer in which the flow is eddying have been continued. The layer is formed on the surface of a flat plate 10 feet wide and 24 feet long installed in the 10-foot wind tunnel. At a distance of 18 feet from the leading edge, the boundary layer is about 3 inches thick. The distribution of the fluctuations of the component in the direction of mean flow has been measured by the usual hot-wire equipment. The component of the fluctuations normal to the plate has been measured by the method of thermal diffusion and some work has been done by the same method on the component parallel to the plate but normal to the direction of mean flow.

Dr. H. K. Skramstad has devised a relatively simple method of measuring the eddy shearing stress, or more specifically, the mean value of the product of the component of the velocity fluctuation in the direction of the mean flow and the component at right angles to the plate. The exploring head is a hot wire at 45° to the direction of the mean flow and measurements are made with the wire in various planes with respect to the direction of the velocity gradient, the wire holder being rotated about an axis parallel to the direction of mean flow. The head is used with the usual compensated amplifier and thermal milliammeter. It can be shown that the eddy shearing stress is proportional to the difference between the maximum and minimum readings which are found at opposite inclinations of the wire in the plane of the velocity gradient. Measurements are in progress with this apparatus.

Modernization of wind tunnel.—It has been obvious for some time that further progress could be expedited with a wind tunnel of low turbulence. The 4½-foot wind tunnel has been rebuilt as a return-circuit wind tunnel, the same 75-horsepower motor being used and the 4½-foot octagonal working section being retained. A contraction ratio of 7.1 was found feasible in the present building. A series of wire screens of no. 18 mesh is used in place of a honeycomb, although provision is made for a honeycomb if its installation proves desirable. There is every indication that the turbulence in this modernized tunnel is less than one-tenth percent of the mean speed.

AERONAUTIC-INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

Investigations.—A report on the results on experiments to determine the performance characteristics of venturi tubes used in aircraft for operating air-driven gyroscopic instruments has been issued as Technical Note No. 624.

The gyroscopic instruments now used in navigating aircraft have been described, and data on their performance given, in a report which is to be submitted for publication as a Technical Note. The report includes a discussion of the new gyromagnetic compass.

A report on the theory and performance of rate-of-climb indicators as now designed is in preparation. The latest instruments indicate rate of climb in the standard atmosphere and are compensated for temperature.

An investigation of corrugated diaphragms has been started during the fiscal year. A satisfactory procedure of manufacturing the diaphragms hydraulically has been evolved. Performance data are being obtained on single, geometrically similar diaphragms of various diameters and thicknesses of beryllium copper and phosphor bronze. The manufacturers of aircraft instruments have cooperated, particularly by furnishing information on methods of manufacture and in suggesting problems for investigation.

Considerable progress has been made in the development of a synthetic lubricant for use in instruments. The lubricant does not spread on brass, steel, or jewels, has a low vapor pressure, and may be usable at temperatures down to about −30° C. Life tests are in progress.

Tests and test methods.—A turntable used to test accelerometers has been modified so that single-component instruments may be subjected to a continuous sinusoidal acceleration and to a part cycle of such an acceleration. The frequency and the amplitude of the acceleration are controllable to an adequate degree. The modification consists of the addition of a fixed pulley concentric with the turntable, and a pulley free to turn at the rim of turntable. When the pulleys are connected by a belt and the turntable rotates, the rim pulley rotates with respect to the turntable. A single-component accelerometer properly mounted on the rim pulley is thus subjected to a sinusoidal acceleration. Varying the diameter of the rim pulley gives an independent control of the frequency of the sinusoidal acceleration. Part cycles are obtained by the use of a friction clutch and stops to control the rim pulley.

An apparatus for subjecting aircraft instruments to a drop test has been designed and constructed.

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Extensive tests were made on experimental resistance thermometers for use in measuring oil and intake-air temperatures. As a result, manufacturers greatly improved the reliability of the instruments under adverse service conditions.

A test apparatus for measuring oxygen delivered by oxygen regulators at various altitudes was designed, orifices being utilized for making the flow measurement.

New instruments.—Development is being continued on an air speed-acceleration recorder and a fuel flowmeter of the orifice type. A stick-force indicator was constructed. A number of pressure gauges were modified to indicate either suction or pressure when applied to the inside of the diaphragm capsule.

SUBCOMMITTEE ON AIRSHIPS

The Subcommittee on Airships formulates and recommends programs of airship research to be undertaken at the Langley Memorial Aeronautical Laboratory, and maintains contact with the work in progress.

The present program provides for an investigation in the Committee's 20-foot wind tunnel of boundary-layer control on airship forms. The investigation is to be conducted on a model approximately 20 feet in length, having a fineness ratio of 6. An arrangement with blower in the nose and an arrangement with stern propeller, with control of the boundary layer by both suction and discharge jets, will be included.

The information being obtained by the Committee's laboratory on the subject of gust intensities and gradients, in connection with the problem of structural loads on airplanes in flight, is of interest also in connection with airship design and operation. This work is described briefly in the report of the Committee on Aircraft Structures.

The subcommittee has kept informed of the latest developments in connection with airship design, construction, and operation, particularly the activities in Germany, where interest in the airship remains active, in spite of the unfortunate disaster to the *Hindenburg*. A technical Note (No. 637) has been issued by the Committee giving the results of an investigation by the Goodyear-Zeppelin Corporation of the fatigue strength of aluminum-alloy airship girders of several different types. A number of translations of German papers dealing with airship problems have been issued by the Committee as Technical Memorandums.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The Subcommittee on Meteorological Problems keeps in contact with the progress of investigations being conducted by the various agencies on problems relating to atmospheric conditions which are of particular

importance in connection with aircraft design and operation.

Atmospheric disturbances and their effect on airplane accelerations.—The study by the Langley Memorial Aeronautical Laboratory of gust intensities and gradients and their effect on the accelerations on airplanes in flight has been continued. Additional data have been obtained in flight investigations with light airplanes. Measurements have also been made on two very large airplanes, and the more recent results indicate that there is no correlation between gust intensity and gradient. One particularly interesting acceleration record obtained on a very large airplane indicated a true gust velocity of approximately 57 feet per second, and the gust was found to reach maximum intensity in a distance of about 150 feet. This gust was downward in direction, and was experienced within a cumulo-nimbus cloud associated with a warm front.

Through the cooperation of a number of air-transport operators, the accumulation of data on accelerations on transport airplanes due to atmospheric disturbances has been continued. The total flying time represented by the records obtained is 57,000 hours. Records have been obtained in air-line operation over practically every part of the United States, on the routes from the East Coast to Bermuda, and to the northern part of South America, over the Andes Mountains, and across the Pacific.

A number of acceleration-altitude recorders recently completed are now being adjusted and calibrated for distribution to various Weather Bureau stations to obtain information as to the relation between gust intensity and altitude. A special instrument has been developed to indicate to the pilot when an acceleration of 2 g is reached, in order that he may observe particularly the atmospheric conditions involved.

Lightning hazards to aircraft.—The possible hazards to aircraft in flight due to lightning has been given special attention by the Subcommittee on Meteorological Problems during the past year. A special meeting of the subcommittee, to which representatives of the air-line operators were invited, was held on November 30, 1937, for the discussion of this problem. A number of experiences of pilots in connection with electrical phenomena were described. It was noted that, while there had been a number of instances of airplanes being struck, the resulting damage to the aircraft was of a very minor nature, and in most cases passengers, and occasionally even the pilots, were not aware of the incident. As a result of the discussion, it was agreed that, although the lightning hazards to aircraft did not appear serious at the present time, it was desirable that the problem be given further study. A Special Subcommittee on Lightning Hazards to Aircraft was therefore appointed, particularly to prepare two programs of investigation—one a short-range program, for the study of problems of immediate importance; and the other a long-range program, to provide for the extension of the present rather meager scientific knowledge of the nature of these electrical disturbances and the ways in which they may affect aircraft in flight.

Under the cognizance of this special subcommittee, investigations are being conducted in electrical research laboratories, of the effect of electric discharges simulating lightning strokes on sheet metal of the type used in aircraft construction. As the first step in the long-range program, information is being collected by means of questionnaires distributed among air-line pilots, as to incidents of electrical phenomena and the accompanying atmospheric conditions.

Ice formation on aircraft.—The study by the Langley Memorial Aeronautical Laboratory of the problem of ice formation on aircraft has been continued. The Committee has recently completed the N. A. C. A. ice tunnel for model tests in connection with this program, and a program of investigation of the aerodynamic effects of ice formation on airplanes and means of prevention or elimination is being initiated. In addition, the feasibility of ice prevention on airplanes by the utilization of heat from the exhaust is being investigated on an airplane in flight.

SUBCOMMITTEE ON SEAPLANES

The world-wide interest in seaplanes of large size has been intensified by the serious discussion of the possibility of replacing the very large and very fast luxury liners by fleets of large flying boats as proposed in the report of the United States Maritime Commission on "Aircraft and the Merchant Marine." The full effects of this proposal, together with those of the announced intention to build machines of practically double the size of existing machines for this country's own transoceanic services, have not yet appeared, but that they will have an important bearing on both domestic and foreign developments cannot be doubted.

In the case of such large craft, with the high wing loadings proposed, the aerodynamic drag of the hull becomes an important part of the total drag, even though the size of the hull may be reduced somewhat by putting accommodations in the wings. The air speed and the fuel required for a given voyage may be quite seriously affected if the requirements for taking off from the water are considered without reference to the more important requirement of low drag in flight. Work on the improvement of the forms of hulls suitable for flying boats of large size is being conducted with these facts in mind.

A large part of the hydrodynamic research in the past year has been devoted to investigations of a specific nature at the N. A. C. A. tank in connection with the development of projected seaplanes. These in-

vestigations were chiefly concerned with the effect of changes in hull form on water resistance and spray and required the use of larger models than may be towed in other tanks in the United States. The N. A. C. A. tank therefore has an important relation to the present development of large military and commercial flying boats.

In the specific investigations as well as the general research program, the projects of immediate interest to the military services have been given first priority. Tests of models of fifteen flying-boat hulls have been completed in the past year. Tank tests of a special nature, not applying to aeronautics but requiring high towing speeds, have also been conducted for the Bureau of Construction and Repair, the Bureau of Ordnance, and the Bureau of Engineering of the Navy Department. The magnitude of the work on these projects caused a reduction in the time devoted to fundamental hydrodynamic problems but gave an opportunity for a more detailed study of some accumulated data and the preparation of the data for publication.

Plant and equipment.—The enlargement and improvement of the N. A. C. A. tank, begun last year, have been completed and a very definite improvement in the operation of the tank has been observed. The basin now has a length of 2880 feet and the towing carriage is powered to travel at speeds up to 80 miles per hour. As anticipated, these features have increased the speed and efficiency of routine testing. In addition, a reserve capacity has been created for hydrodynamic research at speeds greater than are obtainable elsewhere.

The enlargement of the tank has required parallel improvement of the associated equipment. The great length of the basin has necessitated the development of new methods of aligning and leveling the rails, and the suppression of waves and surges. Various refinements and additions have been made to the carriage and the towing gear for the purpose of improving the ease and accuracy of recording the results of tests. A number of auxiliary devices have been constructed for use in the special tests that have been made and the range of adaptability of the equipment has been greatly increased.

Tests of models of representative flying-boat hulls.—In the investigation of the effect of form of hull on hydrodynamic resistance, tests have been made of large models of the hulls representing a variety of methods used to obtain satisfactory take-off performance.

N. A. C. A. model 36 was originally designed to be usued in tests of stub-wing stabilizers and, in order to facilitate fitting different types of stubs, was given a rather long parallel middle-body. This form has proved to be of considerable interest to seaplane designers, not only because the parallel body gives a form of hull that makes it possible to use a convenient arrangement of the interior, but also because the aerodynamic drag as measured in the Committee's twenty-foot wind tunnel over a wide range of angle of attack is quite low. The general tank tests indicate that the hydrodynamic characteristics are favorable and that the water resistance at the hump speed is exceptionally low. The results of these tests are presented in Technical Note No. 638.

Effect of rivet heads on frictional resistance.—The increasing use of flush riveting in the construction of all-metal aircraft has led to a need for information as to the effect of rivet heads on hydrodynamic resistance during take-off. The increase in frictional resistance caused by typical rivet heads was determined at the N. A. C. A. tank by tests of planing surfaces fitted with full-size rivets. The surfaces were towed at the high water speeds encountered by seaplanes during take-off and the relative resistance of the various shapes of head were measured. An analysis of the data, published in Technical Note No. 648, shows that for the rivet heads investigated the increase in frictional resistance is directly proportional to the height of the head. The order of merit of commonly used heads for seaplane hulls is therefore flush countersunk, oval countersunk, brazier, and round. The magnitude of the increase in hydrodynamic resistance depends, of course, on the number of rivets required in the structure.

Uses of tank data.—Investigations of resistance in the N. A. C. A. tank are made general in application by the fact that the models are tested over a wide range of speed, load, and trim. The results are intended to be used as a basis for design calculations to determine take-off resistance and to compare the advantages and disadvantages of various forms of hull. A discussion of possible uses of the "general" test data is presented in Technical Report No. 625. Among the subjects treated in this report are selection of best beam, importance of maximum trim, location of the center of gravity, and comparison of hull lines. It is concluded that the ranges of load and speed employed in the general tests are ample to cover future increases in the size of seaplanes.

In Technical Note No. 643 it is shown that in the solution of some design problems the normal resistance curve for a flying boat may be approximated by two straight lines. By the use of this approximation, charts are developed to aid in the rapid solution of certain problems involving the effect of the shape of the resistance curve on take-off time and distance or the determination of the accelerating forces required to meet specified take-off performance.

The N. A. C. A. trim indicator.—Further experience with the N. A. C. A. trim indicator has emphasized the importance of holding a seaplane at the trims that give least resistance during take-off.

The Committee has constructed and made available for loan to operators and manufacturers a form of trim indicator based on the principle described in Technical Note No. 486. The instruments have proved to be of great assistance in the test flying of large flying boats of new design, particularly those designed for commercial transoceanic service. It is in these types of service and on long-range military seaplanes, which, heavily loaded, must take off with comparatively little reserve power, that a "precision" take-off is essential. A relatively small increase in the total load with which a seaplane may safely take off represents a large increase in payload. Accordingly, it appears that a trim indicator of some form is essential to economical operation of seaplanes in transoceanic service.

In seaplanes that have a large excess power that may be used for take-off, the use of a trim indicator is of much less importance for routine service.

For test flying and in the training of pilots to fly a particular design the optical type of instrument is very useful and is simple and easily adapted to almost any arrangement of instrument board and windshield. An interesting application of the N. A. C. A. trim indicator in this manner was its installation and use for 100 hours of testing in an experimental flying model of a large flying boat.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

As a result of the trend toward larger and relatively more elastic structures in airplane design, the problem of flutter has become increasingly important. The study of this problem at the Langley Memorial Aeronautical Laboratory and by other organizations has been continued during the past year.

The Special Subcommittee on Vibration and Flutter has held two meetings during the past year particularly for the consideration of the subject of flutter. Because of the activities of a special subcommittee recently appointed by the Committee on Aircraft Structures in the study of stresses due to resonant vibration and of the proof testing of aircraft structures in flight, the discussion at these meetings was chiefly limited to the subject of flutter. Reports of progress in the investigation of the subject were presented by the representatives of the various Government organizations. At the second meeting the report recently completed by the Committee's laboratory for issuance in advance confidential form to American manufacturers was presented and discussed.

The flutter problem.—The theoretical investigation of flutter started more than four years ago by the Langley Memorial Aeronautical Laboratory has been extended and generalized. In particular, the scheme of calculation of the critical flutter speed has been simplified to a routine method of calculation that includes the effect of structural damping. A large number of charts have been prepared to facilitate judgment of the effects of the various wing parameters affecting the flutter speed. The effects of the essential parameters in the cases of flexure-torsion, flexure-aileron, torsion-aileron, and flexure-torsion-aileron flutter have been listed and discussed. A series of nearly one hundred experiments in the high-speed tunnel recently completed has shown that the flutter speed can be calculated on the basis of the theory with good accuracy if the parameters are correctly specified or measured. Experiments made on cantilever wings indicate that, by slight modifications, the two-dimensional flutter theory can be used to predict the flutter speed, even for wings of fairly small aspect ratio. A study has been made of the actual mode of vibration involved in flutter and of the respects in which this mode differs from the vibration modes at zero air speed. A number of interesting conclusions have been reached; in particular, that the bending frequency involved in a flutter problem is greater than the frequency involved in a vibration mode at zero air speed, the difference depending mainly on the structural damping. The three-dimensional flutter problem is essentially understood as a problem of minimum boundary value, which fortunately can be handled by slight semi-empirical modifications of the two-dimensional flutter theory.

The problems of identifying the parameters and possible types of flutter on an airplane have been discussed. In the case of the airplane tail assemblage this may be particularly difficult and ground or flight tests may be necessary or desirable. The effects on the flutter speed of large bodies, such as nacelles or floats, on the wing or attached to it have also been investigated, as well as the effect of wing bracing and restraining wires. A report has been prepared presenting the results of this work. This report will include also a theoretical study of forced vibrations and air damping of the wing system, supplying a clearer perspective of the nature of flutter.

Vibration of tapered beams.—An exact solution has been developed for the equation of torsional vibration of a large class of tapered beams. Experimental measurements on five model beams give frequencies in agreement with the theory.

Air damping of vibration.—Fundamental data have been obtained on air damping by vibrating a flat plate in a chamber in which the pressure and the nature of the gas could be changed. The results have been ex-

pressed in terms of two new nondimensional coefficients which play a role in vibration similar to that of drag coefficient and Reynolds Number in steady flow.

Damping of propeller vibration.—A technique and method of analysis of the separate components of damping of the vibration of a freely suspended propeller have been developed. Air damping of the blades and friction in the hub were found to be predominant, in comparison with internal damping in the material of the blade.

Airplane vibration.—A systematic method of measurement and analysis of airplane vibration is being planned in order to be able to predict flutter velocities in actual airplanes. Measurements have been made on the tail assembly of one airplane to determine the frequencies and modes of vibration that determine the flutter characteristics.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

INCREASE IN ENGINE POWER

The power output of air-cooled engines has been limited by the quantity of waste heat that could be dissipated efficiently by the fins to the cooling air. The dimensions of the fins used on the cast-aluminum cylinder heads of present engines are dictated by the casting technique of the foundry. As the final step in the Committee's research on the effect of fin dimensions on heat transfer a method has been developed for attaching preformed metal fins to air-cooled cylinders so that advantage can be taken of the improvement in cooling resulting from large increases in the fin surface. This method removes all restriction in regard to dimensions of the cooling fins that can be used and opens the way to more efficient cooling and to a further large increase in the power of air-cooled engines.

High octane number fuels.—The continued increase in the power output of aircraft engines is principally obtained by the use of premium fuels having high antiknock values. The investigation to determine the maximum permissible engine performance with these fuels has been continued at the Committee's laboratory. The work is being carried out on fuels having octane numbers of 87 to 100 to which various amounts of tetraethyl lead have been added. This investigation is under the cognizance of the Subcommittee on Aircraft Fuels and Lubricants and is described in the report of that subcommittee.

Flow through poppet valves.—The intermittent air flow through poppet valves in engines is calculated by the use of coefficients determined under conditions of steady air flow. The Committee is determining the coefficients of flow for large-diameter poppet valves when operated in the same manner as in the engine. Measurements of the flow coefficients have been made at camshaft speeds from 130 to 1,200 revolutions per minute, at pressure differences up to 7.5 pounds per square inch and at valve lifts from 0.1 to 0.6 inch. The flow coefficients measured with steady flow can be applied to intermittent conditions without correction for valve opening speed or camshaft speed. The results of this investigation are being prepared for publication.

Piston temperatures.—With increase in the power of aircraft engines the aluminum-alloy piston and the cast-iron piston rings are required to transmit proportionally larger quantities of heat to the cylinder wall. An investigation is in progress to determine the important factors controlling piston cooling and to study the effect of engine and cooling conditions on piston temperatures. A method has been developed for attaching thermocouples to the piston and measuring piston temperatures under engine operating conditions. The thermocouple and potentiometer circuit is completed at bottom center for 20° of crank angle through contacts mounted on pneumatically operated plungers. Piston temperatures are being surveyed on a high-output single-cylinder Diesel engine and a modern air-cooled engine.

The 2-stroke-cycle engine.—The use of the 2-stroke instead of the 4-stroke cycle is an attractive method for increasing engine power per unit of displacement. The 2-stroke-cycle engine requires a pump to force the combustion and scavenging air into the engine cylinder. The Committee's research on the liquid-cooled spark-ignition fuel-injection engine has included a study of the effect on performance of variable exhaust-valve and inlet-port timing, scavenging pressure, and engine speed.

The sleeve-valve engine.—The two outstanding advantages of the single sleeve-valve engine over the poppet-valve engine are increased breathing capacity and higher allowable rotative speeds. These characteristics are fundamental requirements of future aircraft engines. The Committee's analysis indicates a decided superiority of the sleeve-valve over the two-poppet-valve type and a somewhat lesser superiority of the sleeve-valve over the four-poppet-valve type, equal flow coefficients being assumed for the sleeve and poppet valves. Since the flow coefficients may differ enough in the two cases to modify these conclusions appreciably, an investigation is in progress to determine the relative coefficients of flow through inlet and exhaust valves and sleeve ports under conditions of steady and intermittent flow.

COMBUSTION RESEARCH

The study of combustion in spark-ignition engines has been continued. New knowledge has been obtained of the combustion under knocking conditions with fuels of high octane number. Particular attention has been

given to the determination of the effect of air flow within the cylinder on the distribution of fuel sprays, the rate of combustion, and the reproducibility of successive engine cycles. Several methods have been investigated for the recovery of waste heat from the engine exhaust gases.

Ignition lag in compression-ignition engines.—The variations in ignition lag and combustion associated with changes in air temperature and density have been studied for a Diesel fuel in a constant-volume bomb. The highest temperature of the bomb approximated that attained in a compression-ignition engine in the usual range of injection advance angles. The ignition lag was found to be essentially independent of the quantity of injected fuel. In order to obtain the best combustion and thermal efficiency, it was desirable to use the largest ignition lag consistent with a permissible rate of pressure rise. Technical Report No. 617 has been published giving the results of this investigation.

Knock in aircraft engines, if continued, may cause preignition, with consequent loss in engine power. The N. A. C. A. combustion apparatus is being used for a series of tests in which conditions causing knock are compared to conditions causing preignition. The preignition is caused by an electrically heated hot spot that can be maintained at a maximum temperature of 1,900° F. It is possible to adjust the hot-spot temperature so that flame proceeding from the spark plug at the opposite side of the combustion chamber causes auto-ignition of the charge at the hot spot. The results of this investigation are being prepared for publication.

Detonation research.—A photographic study of the combustion in a spark-ignition engine has been made, including both schlieren and flame photographs taken at high rates of speed. The results of this investigation have been published in Technical Report No. 622.

Exhaust-gas analysis.—In order to determine the lower heating value of a fuel from its calorimetric heat of combustion it is necessary to know the hydrogen-carbon ratio of the fuel. The methods described in the literature have not given satisfactory results with gasoline. An investigation is being made to develop a satisfactory method of analysis for these volatile hydrocarbons.

An investigation has been made to determine the interrelationship of the constituents of the exhaust gases of internal-combustion engines and the effect of engine performance on these relations. The work has included a study of single-cylinder and multi-cylinder spark-ignition engines and single-cylinder compression-ignition engines. Definite relations independent of engine design and operating conditions were found between the constituents of exhaust gases, air-fuel ratio, water of combustion, and combustion efficiency. Technical Report No. 616 gives the results of this investigation.

Air flow in cylinders.—With fuel injection into the engine cylinder, increased air turbulence assists in atomizing and distributing the fuel spray. The air flow within the cylinder of an engine has been investigated by the use of an engine with a glass cylinder. The data are recorded by motion pictures taken at rates of 2,500 frames per second of the motion of goose down inducted with the inlet air. The shrouded inlet valves considerably increased the distribution of the fuel within the cylinder. The air flow reduced the penetration of fuel sprayed from an annular orifice more than from round-hole orifices. The tangential swirl set up during the inlet stroke was found to continue throughout the compression and expansion strokes. A report is in preparation describing the investigation.

An investigation of the effect of air flow within the combustion chamber of a spark-ignition engine has been conducted on the N. A. C. A. combustion apparatus. By means of spark-schlieren photography and time-pressure records, a study has been made of the effects of air swirl on the combustion propagation. The air flow was produced by shrouds on the inlet valves, and was comparable with that obtained in the glass-cylinder engine. Directing the air in an orderly swirl resulted in great improvement in the reproducibility of successive engine cycles. When the velocity of the intake air was changed by blocking one of the inlet valves without changing the engine speed, there was a considerable increase in the rate of combustion. This same increase was obtained when two inlet valves were used by doubling the engine speed. The results of this investigation are being prepared for publication as a Technical Report.

FUEL CONSUMPTION

For modern long-range aircraft, the fuel load is approximately one-half the useful load, and means must be found for reducing the fuel consumption of the engines under cruising conditions. Research has been conducted on the design and development of an N. A. C. A. indicating fuel flowmeter and a mixture-ratio indicator for use in flight. The effect of operation at various percentages of full-load torque and of rated speed on the minimum specific fuel consumption of an air-cooled engine has been determined.

Fuel distribution.—The use of a fuel-injection system instead of the conventional carburetor should result in more uniform fuel distribution, more rapid engine acceleration, and satisfactory engine operation irrespective of the attitude of the aircraft. An investigation has been completed to obtain a comparison of the performance of an engine with a carburetor, with fuel injection into the inlet manifold, and with fuel injection

into the cylinder. The results of this investigation, which are being prepared for publication as a Technical Note, show that slightly more power was obtained when the fuel was injected into the cylinder because of the increased volumetric efficiency due to the cooling action of the fuel spray. Fuel injection into the cylinder also permitted the use of manifolding that offered less restriction to the air flow. The minimum specific fuel consumption and the cylinder-head temperatures were the same regardless of the method used for distributing the fuel to the air.

The N. A. C. A. fuel flowmeter.—The use of a fuel flowmeter, which indicates instantaneous rates of fuel flow, makes it possible to operate aircraft engines at mixture ratios which will result in low specific fuel consumptions. In multiengine aircraft the fuel flowmeter makes it possible for all engines to be operated at the required rates of fuel flow. The N. A. C. A. flowmeter, which indicates mass rate of fuel flow, has been modified as a result of flight tests of the Army Air Corps and is now considered a satisfactory instrument for use in flight.

Mixture-ratio indicator.—The need in aircraft for a mixture-ratio indicator capable of indicating mixtures both leaner and richer than the theoretically correct mixture has led to the development by the Committee of an instrument capable of indicating any practical fuel-air ratio. A laboratory design has been used successfully and a design suitable for flight testing has been built. A report on the flight performance of this instrument is being prepared for publication.

ENGINE COOLING

The power output and the specific fuel consumption at which air-cooled engines can be operated are dependent upon satisfactory engine cooling. The use of radial air-cooled engines having two and three banks of cylinders for the obtaining of increased power requires a large increase in the effectiveness of the cooling fins placed on the cylinder head and barrel. Particular attention must be given to the cooling of the cylinder barrel to insure satisfactory operation of the piston and piston rings with engines of higher power.

Fin dimensions.—The quantity of heat dissipated from a finned surface is a function of the dimensions of the fins. The analysis being made to determine the best proportions for metal fins for given rates of heat flow has been continued. Thin, closely spaced aluminum fins of optimum proportions were found to give approximately 25 percent more cooling for the same fin weight and pressure drop (4 inches of water) than thicker, correctly proportioned fins having a spacing of 0.14 inch. As the heat dissipation from the cylinder walls of air-cooled engines is proportional to the 0.65 power of the indicated horsepower developed, it follows that a 25-percent improvement in cooling should permit a 42-percent increase in the engine power.

The power required to cool the widely spaced finned cylinders was slightly more than for the closely spaced finned cylinders at a pressure drop of 4 inches of water. For a pressure drop of 12 inches of water, however, the power required to cool the widely spaced fins was found to be approximately 25 percent more than for the fins of optimum design. Although thin, closely spaced fins are difficult to construct by present methods they have been found to be desirable, especially when constructed of metals of high thermal conductivity.

Heat-transfer coefficients.—The investigation to determine the surface heat-transfer coefficients of finned cylinders has been continued. Heat-transfer tests have been conducted on fin surfaces spaced 0.010 inch and on widely spaced, thick-finned surfaces. The object of these tests was to determine the trend of curves correlating the surface heat-transfer coefficients. A report is being prepared presenting the results of this investigation.

Flow around finned cylinders.—In order to obtain a better understanding of the phenomena attending the cooling of air-cooled engines, photographs were taken, by the use of titanium tetrachloride, of the air flow between the fins of a large-scale cylinder model. The double spiral, which has been shown to occur in the flow through bent pipes, was observed. The flow has an outward radial component, away from the cylinder axis, in the region near the center of the fin space, and an inward radial component along the fin surfaces. The radial components of the velocity tend to disappear as the fin spacing is reduced. At a fin space corresponding to $\frac{5}{32}$ inch for a cylinder diameter of 4.66 inches, the radial components were very clearly evident, whereas, at a fin spacing corresponding to $\frac{1}{8}$ inch, no indication of a radial velocity component could be detected. The radial components also disappeared at low velocity.

The problem was studied further by tests on model finned cylinders both in ducts and in the front of an engine cowling. Two Technical Notes, Nos. 649 and 655, show the effect of streamlining the cylinder and the effect of baffle length on optimum fin spacing. Also, it is shown by analysis and from experimental results that cooling on a finned cylinder obeys the same physical laws known to apply to heat transfer for pipes. The solution of a practical case is made comparatively easy by the use of these laws and knowledge of the cooling performance of actual engines.

An investigation has been undertaken to determine the characteristics of the cooling in the front of a cowled engine. The irregular flow existing in this region results in a cooling dependent on air speed in a little-understood manner. The tests show the effect on the cooling of variations of position, fin orientation, fin

spacing, and fin width, with the propeller operated to simulate the cruising condition and the ground condition, and with a spinner to increase cooling pressure in take-off. The results from these tests will show both the nature of the phenomenon and how to make the best use of it for cooling.

Cylinder temperature correction factors.—Technical Report No. 645 has been prepared presenting the results of the investigation made to determine the correction factor for correcting cylinder temperatures of air-cooled engines to a standard atmospheric temperature. The correction factors include flight-test conditions such as level flight, climb, and take-off, the condition with the airplane stationary on the ground, and the conditions of a constant mass flow of cooling air, and of a constant velocity of the cooling air.

Heat-transfer process.—A study has been made of the transfer of heat from the gases of combustion to the cylinder wall, and from the cylinder wall to the cooling fins on air-cooled cylinders. Necessary empirical constants in the heat-transfer equations have been determined from engine tests of a Wright Cyclone cylinder. The effects on cylinder temperature of the following engine conditions were determined: Exhaust back pressure, air fuel ratio, spark timing, carburetor air temperature, engine speed, brake mean effective pressure, cooling-air temperature, and pressure drop across baffled cylinder. Equations were obtained for the cylinder head and barrel temperatures as functions of the engine and cooling conditions. A simple method of comparing the cooling of different air-cooled engines has been developed. A report on this investigation is being prepared.

Blower cooling of engines.—Preliminary studies have been made to determine the relative merits of cooling air-cooled engines by induced flow and by a blower. The necessity for blower cooling at high altitudes with present engines and at sea level with future engines requiring higher pressure drop has been reviewed. Blowers and blower arrangements of several types have been examined with the object of determining their suitability for various conditions with special reference to large airplanes and to flying at high altitudes.

The N. A. C. A. air-cooled cylinder.—The cylinders of air-cooled engines are formed of a cast aluminum head screwed and shrunk onto a steel liner. The dimensions of the fins that can be cast on the head are limited by the casting technique of the foundry. The dimensions of the fins on the barrel are limited by difficulties in machining. The Committee has discovered a method of attaching preformed fins to the cylinder head so that all restrictions as to fin dimensions that can be used are removed and advantage can be taken of the improvement in cooling resulting from large increases in the fin surface. The internal drag horsepower required to cool the N. A. C. A. cylinder is a negligible amount of the engine power developed. This method of construction should make possible large increases in the power output of air-cooled engines without sacrifice of satisfactory engine cooling.

SUPERCHARGER RESEARCH

The altitude selected for flight with transport aircraft is dependent to a large extent upon weather conditions. The requirement of flight at high altitudes has greatly increased the interest in highly supercharged engines.

Performance of superchargers.—Computations have been made to determine the power required and the heat that must be dissipated to maintain discharge-air temperatures of from 60° to 240° F. when an airplane is operating at altitudes from sea level to 80,000 feet with superchargers having a range of compression exponents from 1.0 to 2.0. The boost pressures covered a range from zero to 100 pounds per square inch. The results of this analysis will be applied to an engine to determine the net power and the fuel consumption under these supercharged conditions with gear-driven and turbine-driven superchargers.

Air intercoolers.—The reduction in the antiknock quality of a fuel with increase in inlet-air temperature necessitates the use of an efficient intercooler to reduce the air temperature on supercharged and boosted engines. The present core-type intercoolers have been found to crack and leak at boost pressures of the order of 15 pounds per square inch. A new type of finned intercooler has been tested to determine its heat transfer.

Supercharging of aircraft cabins.—An analysis has been made of the requirements of superchargers for maintaining cabin pressures at high altitude. The results indicate that the Roots-type blower should be very satisfactory for this service because the volume of air required can be controlled by the quantity of by-passed air. The power expended on the by-passed air is small.

COMPRESSION-IGNITION ENGINES

The use of compression-ignition engines in aircraft offers advantages because of the inherent low fuel consumption and the reduction in fire hazard. These two characteristics are of particular importance for transoceanic aircraft. The Committee's research on the compression-ignition engine for aircraft includes a study of the factors influencing the injection and combustion of fuel sprays suitable for this type of engine and the development of a combustion-chamber form that gives good mixing of the fuel and the air. The problems involved in the application of this combustion chamber to the radial air-cooled engine are being investigated.

Combustion research.—The ignition lag and the rate of combustion of the fuel oil in compression-ignition engines can be varied by the addition of small quantities of certain chemicals to the fuel oil. The Com-

mittee has investigated a range of fuel oils, mixtures of fuel oil and alcohol, and fuel-oil dopes to determine their effect on power output and fuel consumption. The engine power has been shown to be practically unaffected by fuel quality; fuels with long ignition lag may be expected to result in rough running. Combustion inhibitors in the form of small percentages of isoamyl nitrate, ethyl nitrate, and tetranitromethane have been shown to lower the rate of pressure rise and to have a negligible effect in increasing power outputs. Alcohol mixed with fuel oil may give a maximum power increase of 4 percent at, however, a prohibitive increase in fuel consumption. In general, it has been found that special fuels are unnecessary in obtaining best performance with a compression-ignition engine; that no gain in power or economy results from their use. A Technical Report presenting the results of this investigation is being prepared.

A study of combustion rates as influenced by the type of fuel, the rate of injection, and the injection advance angle has been started to cover a range of engine speeds from 1,500 to 2,500 r. p. m. The combustion rates are being determined from an analysis of indicator diagrams.

The investigation of ignition lag with the constant-volume bomb has been extended to include several Diesel fuels of different cetane number and different concentrations of Diesel fuel dopes. The results indicate that, at the lower air temperatures in the bomb, the variation in fuel rating order for a series of fuels is somewhat greater than it is in the C. F. R. engine or the N. A. C. A. test engines. The variation in ignition lag over a range in cetane number decreases markedly with increase in air temperature and density. A summary of these results is being prepared for publication.

The 4-stroke-cycle engine.—The problems connected with the adaptation of the N. A. C. A. displacer type of combustion chamber to an air-cooled cylinder having a 5-inch bore and a stroke of 5½ inches are being investigated. Indicated mean effective pressures of 250 pounds per square inch have been obtained at 2,200 r. p. m. with a boost pressure of 10 pounds per square inch. The dimensions and arrangement of the finning on the aluminum cylinder head and the steel cylinder barrel are being studied to insure adequate cooling.

A report describing tests under simulated altitude conditions has been prepared and published as Technical Note No. 619.

A liquid-cooled cylinder has been designed for a single-cylinder engine having a bore of 6⅛ inches and a stroke of 7 inches to investigate problems peculiar to obtaining a high output from a cylinder of a size comparable with the largest air-cooled engine cylinder now in use. The N. A. C. A. displacer-piston combustion chamber will be used with a conventional air-cooled engine and a pushrod-operated valve gear.

As a means of obtaining better utilization of the combustion air, a cylinder head has been constructed embodying a modification of the vertical-disk displacer combustion chamber to allow the use of two inlet and two exhaust valves, and two advantageously located injection valves. With this arrangement all the combustion air will be forced to flow past the fuel-injection valves. Preliminary performance tests of the cylinder head have been made with a single fuel-injection valve mounted in the top of the cylinder for comparison with the performance obtained with the two fuel-injection valves.

The 2-stroke-cycle engine.—An investigation of the effect of variation of the exhaust function has been completed over a wide range of exhaust timings and exhaust-valve cam dwells for several engine speeds and scavenging pressures. Tests have been made to compare the engine performance with the 62 inlet ports in the cylinder liner arranged to direct the air into the cylinder at a common angle or in several bands at different angles to the radial. The best performance was obtained with the single-entry angle of 56° common to all ports. Design alterations to the connecting rod, exhaust valve cams, and inlet ports have been made to make it possible to increase the maximum engine speed from 1,900 to 2,400 r. p. m.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—A spherical bomb with central ignition and auxiliary equipment which yields simultaneous photographic records of the travel of flame and the development of pressure during gaseous explosions has been in use throughout the year. In such a bomb the samples of fuel required are very small, initial conditions may be accurately controlled, and combustion progresses under idealized circumstances, since the spreading flame is undisturbed by turbulence, by contact with restraining walls, or by heat losses other than the unavoidable loss due to radiation. It is therefore possible to study the rate of energy liberation and the speed of flame relative to the remaining unburned charge throughout the succeeding stages of the burning. Although these factors are of fundamental importance in the engine cylinder, they cannot be accurately measured there because of the complicated geometrical configuration of the combustion chamber.

Early experiments with the spherical bomb indicated clearly that high accuracy in the measurement of pressure and flame radius was essential to satisfactory results. The difficulties of attaining such high accuracy in following the extremely rapid course of an explosion necessitated careful development of both the experimen-

tal apparatus and the technique of securing and analyzing the observations.

During this development period, mixtures of carbon monoxide and oxygen were used. The results of these test experiments show not only that the apparatus is capable of serving the purpose for which it was designed, but also indicate some interesting characteristics of this particular explosion process.

In general, the inflammation of a unit mass of this mixture produces an increase in pressure which does not vary greatly with the temperature and pressure prevailing in the unburned charge. However, the energy liberation per unit mass of charge is, without exception, less than would be expected if the burning were completed in the front surface of the flame.

Very early in the explosion, while the rise in pressure is too small to measure, the flame records all show that the spatial velocity increases for a short time. These low initial velocities cannot be accounted for solely by low speeds of advance of the flame into the unburned mixture, but indicate that the amount of expansion or energy liberation per unit mass of charge is much lower in the very early part of the explosion than later on.

The observed behavior of the flame can be explained by assuming that the burning is not complete in the flame front, but continues throughout a zone of considerable thickness behind the front. Other possible ways to study this hypothesis in the light of more direct evidence are being considered.

Records have been made of explosions of the hydrocarbon fuels benzene, N-heptane and iso-octane with air, but these results are not yet sufficiently complete for presentation.

Explosions in tubes.—At the request of the Bureau of Air Commerce, now the Civil Aeronautics Authority, the possible hazards of explosions of maximum-power mixtures of gasoline vapor and air in tubes simulating gasoline-dump ducts were studied. The results indicated that destructive peak pressures are not to be expected in any open-end tubes of dimensions appropriate for dump ducts on aircraft. The ducts should be free from constrictions and from weak, flat areas which might be caused to vibrate violently during an explosion.

Ignition cable.—The energy which must be furnished by the spark coil to cause the spark plug to fire is proportional to the capacitance of the secondary circuit. In many ignition systems the greatest portion of the capacitance is due to the high-tension ignition cable. By decreasing the capacitance of the ignition cable with respect to the engine, less energy is required from the spark coil and consequently less energy from the battery. The capacitance of the cable is decreased by decreasing the size of the conductor.

Measurements have shown current discharges of 30 to 80 amperes across the spark electrodes. These discharges last about one millionth part of a second and consist of 10 to 14 oscillations. After the initial discharge it is desirable to damp out all other oscillations as quickly as possible so as to reduce electrode wear. This is done by the use of a high-resistance conductor.

Decrease in heat transfer from the spark plug to the rubber insulation may be accomplished by using a conductor in the cable which is a poor conductor of heat.

With the decreased cross-sectional area the conductor must be sufficiently strong to make it possible to draw the cable through conduit.

A material which has been found to satisfy these reqiurements is stainless steel.

Spark plugs.—The present methods of testing spark plugs have failed to supply the necessary information for selecting a suitable plug for a particular engine operating under service conditions. New methods of testing are now under investigation.

Electrical equipment.—Studies have been made of low-tension cable, and tests of auxiliary electrical equipment. Facilities have been provided for testing electric motors which operate at speeds in excess of 24,000 r. p. m.

Temperature surveys.—Temperature surveys have been made on all new types of Navy airplanes, both on the ground and in flight. The measurements have been extended to include oil temperature and intake-mixture temperature.

Flow characteristics of fuel lines.—In connection with the aviation vapor-lock project of the Cooperative Fuels Research Committee, the Bureau is investigating the resistance to fuel flow in component parts of aircraft fuel systems as a function of rate of flow and relative amounts of liquid and vapor flowing. The object of this work is to provide the designers of fuel-feed systems with reliable data on gasoline flow under vaporizing conditions.

Engine testing.—For the information of the military services, two small experimental engines were subjected to approximate altitude tests. These engines were submitted in connection with the development of auxiliary power plants for use in large aircraft. At the request of the Matériel Division of the Army Air Corps, a series of 50-hour endurance tests were conducted on the torque stand on a 9-cylinder radial aircraft engine, for the purpose of comparing different oils and two types of oil tank.

Measurement of surface wear.—A new method of evaluating surface wear, by successive measurement of minute indentations made in the surface with a diamond point, has been developed. This method seems particularly promising for the measurement of piston and

cylinder wear in engines, where measured clearances, including as they do the effects of piston growth and cylinder distortion, frequently give highly misleading indications as to wear.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Engine performance with iso-octane fuels.—As mentioned above in the report of the Langley Memorial Aeronautical Laboratory, the Committee has continued the investigation to determine the maximum permissible engine performance with fuels having octane numbers of 87 to 100 to which tetraethyl lead has been added. Data have been obtained on a pent-roof combustion chamber and on a flat-disk combustion chamber. The results have indicated that the knocking characteristics of any one fuel in a given engine can be expressed as a curve showing the critical relationship between the inlet-air temperature and the density of the combustion gases at top center. From this curve it can be determined whether or not various combinations of inlet-air pressure, inlet-air temperature, and compression ratio will result in knock. This method (described in Technical Note No. 647) of expressing the knocking characteristics of a fuel has been suggested as a means of rating fuels.

The effect of irregular spark timing on the knocking properties of fuels has been discussed in Technical Note No. 651. It was found that on the Committee's high-speed engine a change of one crankshaft degree in spark timing was equivalent to a change of 0.4 pound per square inch in allowable inlet pressure.

The investigation of the correlation of the effects of the engine variables on the knocking limits of the fuel is being conducted on a high-speed C. F. R. engine. Tests are being made to determine the effect of mixture density and temperature on knock at various engine speeds. Tests are also being conducted on four fuels each having an octane number of 100 by the C. F. R. method. The fuels differ, however, in the amount of tetraethyl lead added to the base fuel to bring the octane number to 100.

Stability of aviation oils.—The original program has been completed on the investigation of the stability of aircraft engine lubricating oil, conducted by the National Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy. From extensive laboratory data obtained on a large number of aviation oils by the use of several variations of each of three general methods, a laboratory method has been found which gives a satisfactory correlation with data on the same oils obtained in a Pratt and Whitney Hornet engine. This correlation has been verified by service tests, and makes possible the prediction of the service stability of an aviation oil from the results of comparatively simple laboratory tests.

Additional information has been obtained on the evaporation losses which occur at temperatures approximately those on the cylinder wall near the combustion chamber and around the upper piston ring. These data throw considerable light on the effect of refining processes on oil consumption.

Work on the stability of compounded oils has been continued and information on this characteristic has been obtained for many of the compounding materials found effective commercially for reducing engine wear.

Ring-sticking with aviation oils.—Preliminary work at the National Bureau of Standards with a single-cylinder engine has indicated the possibility of evaluating the ring-sticking characteristics of aviation oils by tests of this type, and of investigating the effect of compounding agents in reducing the tendency to cause ring-sticking.

Extensive information has been obtained on the thickening of oils at the high temperatures encountered around the upper rings and a considerable amount of useful data obtained relating the extent of thickening to the processes used in manufacturing the oil.

Wear, oiliness, and corrosion characteristics of aviation oils.—In cooperation with the Bureau of Aeronautics and the Air Corps, work has been continued at the National Bureau of Standards on the investigations of the relations between oil characteristics and bearing corrosion, with special reference to master rod bearings, and wear reduction of cylinder-wall and piston-ring materials. Most of the necessary equipment has been constructed and assembled, and some preliminary information has been obtained, but the work has not progressed sufficiently far to permit any conclusions to be drawn as yet. Emphasis is being placed on the effects of compounding agents in reducing bearing corrosion, wear of cylinder walls and piston rings, and frictional losses in master-rod bearings.

The first run of an R–1535 engine to study the problem of wear with various oils was terminated after 35 hours by a mechanical failure. Further running under different conditions and with a smaller engine is being considered. In spite of the fact that no other data which are exactly comparable will thus be obtained, very valuable information has been collected regarding the relative merits of wear determination by the indentation method as well as by conventional gauge measurements. The former is a new method and consists of making almost microscopic indentations in the wearing surfaces, and the surface wear is then accurately indicated by optically measuring the changes in the lengths of these marks. By this method excellent data are obtained on the actual thickness of the material worn off the surface, and the results so far indicate that on engine cylinders and pistons even the most accurate conventional gauge measurements may be deceptive in the region of small total wear, or

where the differences in wear are small. Since in the case of the R–1535 engine test both methods were used, some very interesting data on distortion as well as on wear are being obtained. The report on the tests with this engine is in preparation.

REPORT OF COMMITTEE ON AIRCRAFT MATERIALS

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

Effect of weathering on light-metal alloys.—A report on this investigation has been prepared for publication summarizing the effect of continuous exposure to the weather on aluminum and magnesium alloys in sheet form as used in aircraft. The tests included the various alloys and protective surface treatments commercially available when the investigation was started. The results of the five-year program have definitely established the relative merits of most of the commonly used alloys and protective treatments with respect to atmospheric corrosion resistance, as follows:

(a) Aluminum alloys.—Aluminum alloys containing magnesium as the essentially alloying constituent are very resistant to attack even under the very severe exposure conditions prevailing in many of the tests. They head the list of all the alloys tested. Next in order are the alloys containing magnesium and silicon. The third group of alloys, those containing copper, are susceptible to intercrystalline corrosive attack and, when in thin-sheet form, often lose much of their initial tensile strength and ductility as a result of a corrosive attack of this character.

(b) Surface treatment.—For prolonged exposure of aluminum alloys, a surface layer of pure aluminum is overwhelmingly superior to any other protective method available. Of the other protective measures, the most satisfactory ones depend upon surface oxidation. This forms an excellent basis for the adherence of coatings applied thereon. The surface film produced by anodic oxidation is by far superior to any other of this type of treatment, although it too should be followed by another coating for most satisfactory service. All oxide surface films can be greatly improved by "sealing." The use of the chromic acid solution in one type of anodizing treatment is excellent for this purpose, according to the test results.

(c) Applied organic coatings.—All the various kinds of vehicle of the varnish type used in the applied coatings yielded excellent results when pigmented with aluminum. Other pigments were decidedly less satisfactory.

(d) Magnesium alloys.—Magnesium-alloy sheet properly protected by (1) suitable surface treatment to obtain adherence of the coating, (2) a primer, and (3) surface coating of the kind mentioned above, withstood very satisfactorily five years' continuous exposure to the weather in a tropical marine location (Coco Solo, Canal Zone).

New series of exposure tests of aircraft metals.—During the year a comprehensive series of exposure panels was installed, with the cooperation of the Bureau of Aeronautics of the Navy Department, at the Naval Air Station at Hampton Roads, Virginia. The materials used are representative of commercial aluminum and magnesium alloy and of stainless-steel sheet of various kinds. The light-metal alloy sheets are exposed (a) in the bare condition, (b) after being coated in accordance with the principles established in the previous work, (c) joined together in couples, the components of which are of different compositions, by spot welding and by rivets of various compositions. This last phase of the test is considered to be of major importance in this series of exposure tests. The stainless-steel panels are exposed in the same manner, except that no coatings have been applied. To provide information on conditions such as those involved in the use of sea aircraft, two types of exposures have been used. In one series, the panels are exposed continuously to the marine atmosphere; in the second, the racks are located at mean tide level so as to provide total immersion at high tide followed by free exposure to the air at periods of low tide. Samples are removed at intervals for testing in the laboratory to determine the changes in surface conditions resulting from corrosion and the attendant changes in mechanical properties. Yearly reports summarizing the results are planned.

Structural changes in aircraft metals occurring as a result of service stressing.—A report has been prepared for publication by the Committee entitled "Effect of Working Stress on the Impact Resistance, X-ray Diffraction Patterns and Microstructure of 25S Aluminum Alloy." The aluminum alloy 25S, because of its importance as a propeller material, was the material tested. In general, the results were negative in their nature. No evidence was obtained to indicate a decrease in impact resistance, either at normal or subzero temperature, as a result of continued fatigue stressing below the endurance limit; nor was any indication obtained by X-ray diffraction examination of impending fatigue failure of material severely fatigue-stressed but without actual crack formation. Certain suspected microstructural features first observed to occur in used propeller blades, but later noted in unused blades, were found not to be indicative of inferior mechanical properties. Work on this subject on the possible deleterious effect of continued fatigue-stressing has been extended to chromium-molybdenum steel (SAE X4130) of the type used extensively in aircraft construction.

Effect of sub-zero temperatures on aircraft metals.—Study has been continued to determine the factors responsible for the decrease in impact resistance of

ferritic steels with decreasing temperature and to endeavor to improve this condition. The results of tests of welded steels at low temperature, −80° C., indicate that this question is one of real importance in welded structures.

Elastic properties of high-strength aircraft metals.—An extensive report has been prepared for publication summarizing the work done in this investigation. It is entitled "Elastic Properties of 18–8 Chromium-Nickel Steel as Affected by Plastic Deformation." A new approach is offered for the determination of the elastic properties, yielding results of a more practical and useful nature than those by more conventional testing procedure. Despite the fact that the austenitic steels, of which this is a representative, possess only pseudo-elastic properties, their other characteristics make them very desirable for many structural applications.

Durability of magnesium.—The durability of magnesium alloys, especially in sheet form, is largely determined by the surface protective measures used in connection with such materials. This is most marked in a marine atmosphere but, as mentioned above, properly protected magnesium alloy in sheet form has withstood continuous exposure under tropical marine conditions for five years without serious impairment of its properties. Study has been continued with the hope of simplifying and improving current methods of surface treatment of magnesium. It has not yet been deemed advisable, however, to substitute a new process for the widely used anodic treatment in the dichromate-phosphate solution, despite the encouraging results obtained.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The problems investigated by this subcommittee at the National Bureau of Standards during the past year included the development of a flexible substitute for glass, of a substitute for silk for parachute shroud lines, and of a plastic material for aircraft structures.

Two items mentioned in the 1937 report are omitted from this. The problem of finding a substitute for linen webbing is considered completed. Materials for acoustical and thermal insulation are now in general use and are considered satisfactory when first installed. The subcommittee is watching their performance to see whether or not they deteriorate with age under service conditions.

Development of flexible substitute for glass.—During the current year efforts in connection with the development of a flexible substitute for glass for windshields have been largely concentrated on the development of improved compositions of the cellulose acetate and methyl methacrylate types, particularly with regard to shrinkage and weathering characteristics. This work has been carried on with the active cooperation of the manufacturers' laboratories and it is believed that the marked improvement which has been noted in the commercial sheets in recent months can be attributed at least in part to the stimulus which this investigation has provided to the development of better formulations and methods of processing.

It has been found that the tendency of the early methyl methacrylate resin to craze in service was due either to the presence of a small amount of monomer or solvent in the sheet or to strains left in the finished sheet or produced during forming operations. Seasoning the sheet at a high temperature and careful control of the temperature during shaping have eliminated the crazing, at least for the two-year period during which such sheets have been exposed. Accordingly, heat seasoning of the methacrylate sheets has been adopted by the manufacturers, with the result that today these products have improved surface hardness and freedom from crazing and undergo practically no shrinkage when exposed to the weather.

For the cellulose acetate sheets, the primary problem has been one of increasing the resistance to sunlight or weathering in general. In order to study the effect of various plasticizers on this property, approximately 60 experimental sheets were made by cooperating manufacturers during the course of the year. These are now being examined for weathering stability by means of both accelerated and roof exposure tests, and some of these have been found to be remarkably resistant to deterioration by ultraviolet light. The tests have also indicated that by suitable heat seasoning of the cellulose acetate sheet during manufacture shrinkage as observed in laboratory heating tests can be reduced to a small percentage of that now obtained with the commercial products. Specimens of the original and of the heated materials have been placed on the roof to observe their further shrinkage upon aging.

A reliable accelerated aging test for transparent plastics would be very helpful in evaluating proposed new windshield materials and in experimental work on improvement in formulation of existing types. Accordingly, considerable emphasis has been placed recently on the determination of the effect of ultraviolet light from various sources on the deterioration of plastics. Mercury arc, carbon arc, and so-called sunshine bulbs have been used as the light source, and both temperature and humidity conditions have been varied. Specimens of the transparent plastics used in these tests are at present being exposed at Coco Solo, Miami, and Washington. It is expected that as a result of this experimental work a laboratory test can be developed which will enable the suitability of new products for use as windshields on aircraft to be speedily determined.

Substitute for silk shroud lines for parachutes.—Cotton shroud lines have been made which, though of lower strength-weight ratio than is obtainable from silk, appear to have equal or greater ability to absorb shock. These cords are to be given a practical service test.

New types of synthetic fibers which are being produced on a semicommercial scale have great promise for shroud lines. Arrangements have been made for the production of some experimental lines from these fibers.

Development of plastic material for aircraft structures.—An investigation was initiated to develop a reinforced plastic which will be satisfactory for airplane construction with respect to strength, stiffness, bending endurance, resistance to flow under load, and related properties. The major problem of devising a molding process adaptable to the fabrication of large sections is being given special consideration. The preparation of specimens with various types of resins and reinforcing agents and the determination of the stress-strain curves of these experimental materials both in tension and in compression is in progress.

REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES

During the past year there was organized under the Committee on Aircraft Structures a Special Subcommittee to Make Survey of Technique and Equipment for Elastic Examination of Large Aircraft Structures in Lieu of Destruction Tests. This subcommittee was appointed for the purpose of maintaining active contact with developments in strain gauges and other equipment necessary to determine strains and other elastic phenomena in complete airplane structures. In addition, the subcommittee recommends financial support, when considered desirable, for those developments that show promise of producing useful instruments for work of this nature. As a result of recommendation of the subcommittee, research at the Massachusetts Institute of Technology to develop electrically strain-sensitive materials and technique for their application has been sponsored.

There has also been organized under the Committee on Aircraft Structures a Special Subcommittee to Direct Research in Applied Structures, for the purpose of making recommendations as to special facilities which should be made available for aircraft structural research, and as to the program of investigations to be conducted. This subcommittee is maintaining close contact with investigations of aircraft structural problems, and in particular with the research programs of the Langley Memorial Aeronautical Laboratory and the National Bureau of Standards.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

STRESSED-SKIN DESIGN

When the National Advisory Committee for Aeronautics was established in 1915, relatively little was known regarding aerodynamics and aircraft engines as compared with the knowledge of structures. As a consequence the Committee directed its first researches mainly in the less well known fields. With the introduction of the stressed-skin, or monocoque, type of structure in recent years, there has developed a need for research in airplane structures. Accordingly, the Committee has for some time been conducting theoretical research in structures at Langley Field. In order to supplement this theoretical research, facilities are now being provided where a limited amount of structural testing can be done to check the theories developed.

Stress analysis of monocoque structures.—It has been known for some time that the stress distribution in box beams is affected materially by the shear deformation of the flanges, a phenomenon sometimes referred to as "shear lag." The subject has been investigated theoretically and experimentally.

The investigation of simple structures, which was mentioned last year, has been extended to cover more complicated structures. Technical Report No. 636 presents a method of stress analysis applicable to structures, such as wings or fuselages, and describes strain-gauge tests made to verify the theory.

General stability of monocoque structures.—One of the important problems that confronts the designer of monocoque structures is that of the stiffness required of the transverse members to hold the stiffened shell in shape. As these members are not required to carry loads of any appreciable magnitude, the problem is mainly one of elastic instability. The problem has been studied theoretically with the result that solutions have been obtained for certain cases. Tests are now being planned to check the design formulas derived.

Fixity coefficients for panel columns.—In the design of the compression panels in stressed-skin wings and monocoque fuselages, one of the problems is to determine the end fixity of these parts. As a preparation for this study, the end fixity of compression members in continuous beams and rigid-joint trusses have been studied. In this connection two papers have been published: Technical Note No. 617, which is concerned with the basic theory, and Technical Note No. 652, which contains a set of tables that are necessary for the solution of practical problems.

Extensions have recently been made to the theory presented in Technical Note No. 617 to render it more

useful in the solution of practical problems. For example, when the equation for neutral stability is tested for three assumed loads, each of which is less than the true critical load, it is possible to estimate the true critical load. A paper on this method of estimating the critical load is now in preparation.

The essential principles of the foregoing theory are now being applied to determine the critical buckling strength of parallel columns in stressed-skin structures, with the result that practical formulas have been derived for some cases.

Skin-stiffener panels.—Theoretical studies of the compressive strength of skin stiffener panels have been continued. Most of the work on this problem, however, has been experimental. Preparations are being made to check the theory for the strength of skin-stiffener panels in compression presented in Technical Report No. 582. When these tests are completed, it will be possible to plan more satisfactorily the program for future studies of this problem.

Analysis of experimental observations in problems of elastic stability.—In 1932 Southwell presented a method for the analysis of experimental observations in problems of elastic stability. Briefly, the method is concerned with the interpretation of simultaneous readings of load and deflection. As therein presented, the method requires that the initial deflection reading be taken at zero load. In the vicinity of zero load, deflection readings are usually somewhat questionable. The deflection readings are reliable only after enough load has been applied thoroughly to seat the specimen and the loading fixtures. Furthermore, it is not always convenient to take the initial deflection reading at zero load. Also, something may happen to render the first few readings valueless and it may not be practicable to repeat them. For use under such circumstances, a more general method has been devised wherein the initial readings may be taken at any load less than the critical load. This general method has been presented in Technical Note No. 658.

Buckling above the elastic limit.—In nearly all practical structures the designer tries to proportion the parts so that the material is efficiently used. This objective requires that the cross-sectional area of each part be as small as possible. The result is that much of the material is subjected to stresses above the elastic range. The problem of buckling above the elastic range is therefore a very important one.

A number of theoretical studies have been undertaken in the investigation of this problem. One part of the theoretical study has been to determine what parts of the problem should be experimentally studied.

Local failure of compression members.—Several extensive studies have been made of local failure in compression members of thin metal. The greater importance attached to other problems has delayed completion of these investigations. It is hoped, however, that during the coming year at least one paper on this subject will be published.

STRUCTURAL LOADS ON AIRPLANES IN FLIGHT

Applied loads on airplane structures—gust loads.—Coordinated measurements of acceleration and air speed on transport airplanes have been continued, and the total flying time represented on the records has been extended to 57,000 hours. In several cases high accelerations were recorded on the largest airplanes coming within the scope of the program, the most outstanding being an acceleration of -2.2 g, measured from the $+1$ g level-flight datum, on a four-engine airplane of 52,000 pounds gross weight. The effective gust velocity of -38 feet per second in this case occurred within a cumulo-nimbus cloud associated with a warm front.

Gust research.—Measurements of gust intensities and gradients on light airplanes have been continued and the data extended. Meanwhile tests in the gust tunnel on models of these airplanes have indicated minimum and maximum limits of gust gradient beyond which the airplane is incapable of indicating accurately the true gust characteristics. The tests have therefore been extended to include measurements on two very large airplanes in order to obtain data beyond the limitations of the smaller airplanes. The more recent results of this research indicate that there is no correlation between gust intensity and gradient, so that the problem is reduced to the question of finding the steepest gradient likely to occur coincident with the stronger gusts. In one outstanding case measured on a very large airplane, a true gust velocity of approximately 57 feet per second was found to reach maximum intensity in a distance of about 150 feet.

Gust tunnel.—During the past year the gust tunnel has been provided with means for controlling the velocity distribution so that gusts ranging from those having substantially a sharp edge (viz, gusts reaching maximum velocity in a distance from one-quarter to one-half the chord length of the models) to those having mild linear gradients, can be represented. The equipment has been developed so as to function very satisfactorily and a number of tests have been made.

In sharp-edge gusts, Küssner's original theoretical results have been verified and his assumptions applicable to finite rectangular wings have been found to apply for aspect ratios as low as 2.0. The experimental accelerations in general are very slightly below the theoretical ones. It has also been found that the theoretical results are valid for tapered wings when the mean geometrical chord is used as the basis of the calculations.

In gusts with moderate gradients, the effect of pitching has been determined on a number of models, and relations between gust gradient, airplane size, and acceleration have been evolved, with pitching taken into account. In a few cases anomalous results indicate the existence of influences the nature of which is not yet understood; it has been concluded, for this reason, that, in general, calculations based on the usual assumptions or data on stability are likely to be in error, and that close approximations to the true motion must be determined by experiment.

Tests of a model equipped with a dynamically overbalanced flap indicated that such a gust-alleviating device is ineffective in sharp-edge gusts but causes appreciable reduction in acceleration in gusts with moderate gradient. In the particular case investigated, the acceleration was reduced about 40 percent in a gust reaching maximum intensity in 14 chord lengths with a flap having a chord 10 percent of that of the wing.

Load distribution.—A study of the variation of the net wing loads under combined angular and normal accelerations has been undertaken. The study includes consideration of the loading conditions produced by unsymmetrical landings, aileron deflection, and unsymmetrical gusts, as well as conditions produced by angular accelerations in yaw. The results are to be applied to the analysis of several types of airplane for the purpose of determining those conditions, in addition to the usual symmetrical loading conditions, that should be included in a complete rational analysis of the structural strength for each respective type.

Tail loads.—The problem of tail loads in maneuvers has been reviewed in the light of present available information on the controlling physical factors. Flight tests have been planned for the purpose of verifying computed results.

The problem of tail loads in gusts is receiving attention experimentally. A bomber-type airplane has been equipped with a special vertical tail unit permitting the measurement of gust loads during normal flight in rough air. A number of records have been obtained.

Hull pressures and stresses.—In addition to several routine tests to determine hull pressures and accelerations during rough-water landings of new seaplanes and flying boats, an extensive installation of recording instruments has been made on a large flying boat. These instruments include bottom-pressure gauges, strain gauges, and several instruments for measuring the motion of the airplane in landing and take-off. A large number of tests have been made but the data have not yet been fully analyzed.

Dynamic overstress.—Measurements of acceleration and wing stress have been made on an M–130 flying boat (*Hawaii Clipper*) of Pan American Airways during a round-trip flight between Alameda, California, and Hong Kong. As this airplane is large, with a wing frequency in bending of only 4.33 cycles per second, the results supply significant practical evidence of the existence or absence of overstress in gusts resulting from rapid application of load. Although several strong, abrupt gusts were encountered at air speeds as high as 200 miles per hour, no evidence of overstress was observed, the measured stresses showing excellent agreement with the datum stresses at unit load factor multiplied by the measured gust load factors determined by an accelerometer.

Stress history.—A fairly complete stress history obtained during the flight on the M–130 flying boat provided data applicable to the problem of fatigue of airplane structures. Although the fatigue resistance of the structure under flight conditions is not definitely known, it can be stated on the basis of existing data on this subject that fatigue failure resulting solely from stress variations in rough air (viz, in the absence of serious vibration) does not appear to be a possibility within the probable life of any airplane.

NATIONAL BUREAU OF STANDARDS

Aircraft tubing.—Two reports on tubing used in aircraft have been published within the last year, one on column strength, as Technical Report No. 615 of the National Advisory Committee for Aeronautics, and the other on crinkling strength and bending strength, as Technical Report No. 632. The report on column strength covers round and streamline tubing of four different materials, namely, chromium-molybdenum steel, 17ST aluminum alloy, stainless steel, and heat-treated chromium-molybdenum steel. The report on crinkling strength and bending strength is the result of tests completed during the year on round chromium-molybdenum steel and 17ST aluminum-alloy tubing.

Both reports give an account of the tests, including the laboratory work and the subsequent analysis of the laboratory data; they consider the theoretical aspects of the problem; and finally, empirical formulas are given for the column strength, in the first report, and for the crinkling strength and the bending strength in the second report, in terms of the dimensions of the tubes and the yield strengths of the materials. These formulas have also been written for materials just complying with applicable Navy Department Specifications.

Considerable attention has been given to the testing of round aircraft tubing under combined axial, compressive, transverse, and torsional loading. Apparatus has been designed and constructed for such tests.

Round heat-treated chromium-molybdenum steel tubing has been donated by the Summerhill Tubing Company for the purpose of making crinkling tests, bending tests, torsional tests, and tests under combined loading.

Flat plates under normal pressure.—Seven circular plates of 17ST aluminum alloy 5 inches in diameter

and ranging in thickness from 0.021 to 0.072 inch have been tested under normal pressure with their edges clamped, and the measured deformations have been compared with those predicted from Way's theory of such plates. Way's curves were extended to ratios of center deflection to plate thickness equal to 1.5. Satisfactory agreement was obtained up to center deflections of this order between the observed and calculated center deflections. Comparison of the measured and the calculated distribution of radial stresses for one of the plates also showed close agreement for all portions of the plate except those near the edge, where the measurements are most difficult to make and where errors due to deviations from the ideal clamping conditions have a maximum effect.

A plot of the "Navy yield pressure" (an arbitrary measure of appreciable yielding obtained from the pressure-set curve) for these plates, led to a simple empirical relation which described this quantity as a function of the tensile strength of the plate material and the dimensions of the plate within ± 20 percent.

With the existence of such a relation for circular plates it appears probable that a similar relation could be derived from tests of rectangular plates in the presence of nearly ideal clamping conditions. The tests of square plates made to date gave values for yield pressure scattering within ±70 percent about the same curve as that derived from the tests of circular plates.

Beams and stressed-skin research.—A report of the study of strain distribution and buckle shape, and stringer deformation in the two sheet stringer panels has been submitted to the National Advisory Committee for Aeronautics for publication as a Technical Note. The report includes a comparison of the measured buckle shape and measured strain distribution in these panels with those given by theories of S. Timoshenko, J. M. Frankland, and K. Marguerre. The measured effective width was compared with that given by nine different formulas for effective width that have been presented in the literature. Southwell's method of plotting was applied to the measurements of stringer deformation and stringer strain. In many cases the points on the plots of twisting and bending rotation of the stringers and of bending strain were scattered about a straight line throughout their entire range, and in all these cases the slope of the straight line was in agreement with the observed measured buckling load of the panel. It should be mentioned in this connection that the failure of these particular panels occurred at stresses considerably below the yield strength of the material.

An experimental study of the effect of rivet spacing and of spot spacing on the strength of sheet-stringer panels has been started with tests to failure of four 24ST aluminum alloy panels. The rivet spacing in these particular panels was unusually large, ranging from 2 to 6 inches, and consequently the first pronounced deformation of the sheet was a buckling between rivets. This occurred in every case at a stress close to that predicted from Howland's assumption that the sheet between rivets should buckle like an Euler column with clamped ends.

Fourteen more panels remain to be tested. The whole series includes rivet spacings from 0.5 to 6 inches, spot spacings from 0.75 to 4 inches, sheet thicknesses from 0.024 to 0.107 inch, and stringer spacings from 1.5 to 4 inches.

Generalization of Southwell's method.—Analysis of the observed deformations of the stringers in the sheet-stringer panels tested at this Bureau had indicated that the elastic buckling loads of many structures may be predicted from deflection or strain readings below the buckling load by making use of a method of plotting which was developed by Southwell for the particular case of the instability of an initially bent column. An explanation for the wide applicability of this method of plotting has been derived by L. B. Tuckerman from Westergaard's general theory of the buckling of elastic structures. This generalization of Southwell's method also indicates more clearly the limitations of the method. It shows, also, how the method may theoretically be used to derive not only the lowest buckling load but buckling loads of higher order as well. This was checked experimentally by obtaining the first, second, and third Euler loads from strain readings on bent columns and the first and second Euler loads from strain readings on an eccentrically loaded column. It seems doubtful, however, whether the experimental accuracy on complicated structures will be sufficient to make this possibility practical. A paper describing this work has been prepared for publication in the Journal of Research of the National Bureau of Standards.

Monocoque boxes.—Experimental work on this project during the past year has been limited to column tests of extruded 24ST aluminum-alloy H-sections with freely supported ends and with elastically restrained ends. Similar sections are used as stiffeners in monocoque constructions. The tests were desired in connection with Lundquist's analysis of sheet-stringer panels under compression.

The results of the tests were embodied in a detailed report which has been submitted for publication as a Technical Report of the National Advisory Committee for Aeronautics. The report gives an account of the tests and the subsequent analysis of the laboratory data, and also an empirical nondimensional column formula (straight-line) for the plastic range and the resulting formula for E/E. These formulas are also presented in the conventional form to apply to material just complying with Navy Department Specification 46A9a.

The experimental work on the monocoque boxes themselves has been delayed by the difficulty of obtaining

suitable specimens. Because of the cost of the specimens, it was found that for the present only one box could be procured, and it was decided to make this of more or less typical construction, 10 by 24 by 95 inches, of 24ST material, with approximately five bays spaced by bulkheads of typical stiffness.

The tests which are to be made with this specimen during the coming year are to include strain explorations under axial load, under pure bending about the lift axis, under bending about the lift axis combined with bending about the drag axis, and under bending about the lift axis combined with shear. The load is to be kept below the ultimate in each test so that the specimen will still be intact after each loading. After the completion of all the tests within the elastic range the specimen is to be tested to failure in end compression.

Strength of riveted joints in aluminum alloy.—In view of the interest of airplane manufacturers in riveted joints of the flush type the work done on this investigation during the past year has been limited chiefly to determining the mechanical properties of flush riveted joints and preparing a report of the results.

Shearing and tensile tests have been completed on joints fabricated by eight manufacturers in accordance with their own practice. Among the types represented are two types of 78-degree rivets, two types of 100-degree rivets and the "flush brazier" rivet, all used with various combinations of counterpressed and countersunk sheets. Joints employing brazier-head and special-oval-countersunk-head rivets were fabricated at the National Bureau of Standards and were included for comparison.

The shearing strength of joints having counterpressed sheets was considerably greater at some values of the ratio of rivet diameter to sheet thickness than the strength of joints made with brazier-head rivets. There was a marked decrease in the shearing strength with increase of this ratio. In several joints the sheet was found to contain injurious cracks which originated during the counterpressing operations.

A report showing the mechanical properties in graphical form, together with photomacrographs and drawings, is being prepared.

Airplane vibration.—Close cooperation was maintained throughout the year with the Bureau of Aeronautics in its program for the development of suitable equipment for picking up and recording vibration amplitudes and strains on airplanes in flight. A number of schemes for accomplishing this were discussed at conferences between the Bureau of Aeronautics, representatives of various commercial organizations, and representatives of the National Bureau of Standards.

As part of this program calibration tests were carried out on strain gauges of the electromagnetic type and of the variable-inductance type, both constructed by the Sperry Gyroscope Company, as well as tests of the carbon-resistance strain gauges known as "Ess strips" which have been developed by Professor de Forest.

In connection with the calibration tests a device was constructed for subjecting dynamic strain gauges to uniform sinusoidal strains up to 0.001 over a range of frequencies from 0.05 to 200 cycles per second. The device has been subjected to preliminary trials and a number of changes in design have been made to give a more nearly uniform axial strain on the strip of sheet metal to which the gauges are attached.

Investigation of fatigue resistance of fabricated structural elements of aircraft.—The method and test equipment developed for testing the fatigue strength of aluminum-alloy wing beams were described in detail in Technical Note No. 660. This paper also gives the results of tests on two wing beams that had been removed from an airplane. Further tests are in progress.

The magnitude of the alternating axial load applied to the two beams tested was computed from the amplitude of strain as indicated by 2-inch Tuckerman optical strain gauges, and also, on the assumption that the motion was sinusoidal, from the mass, amplitude, and frequency of one of the terminal weights. The results of the two methods of computation differed by 8 percent and 10 percent in the two cases. The results of the second method were the smaller in both cases. The overall strain could not be used because of uncertainties in the effective length due to reinforced portions along the beams and to unknown deformations at the terminals. A fourth method, contemplated in future tests, consists in determining the mass and acceleration of one of the weights directly. This would require an accelerometer of very short relaxation time. A tentative design for such an instrument has been made.

The test program is somewhat complicated by the fact that some of the specimens contain asymmetric reinforcements near the center. As a consequence, the centroidal axes of these beams are not straight, and centering the load requires a large displacement of the centers of gravity of the terminal weights from the line connecting the centroids of the end sections. It is desirable to include these asymmetric reinforcements in the test length of the specimens in order to investigate the possibly serious stress concentrations due to their presence in the airplane structure. Terminal attachments have been designed to permit ample adjustment of the transverse displacement of the terminal weights.

Tensile and compressive properties of duralumin, magnesium and alloy steels.—A paper entitled "The 'Pack' Method for Compressive Tests of Thin Specimens of Materials Used in Thin-walled Structures" is in process of publication as a Technical Report of the National Advisory Committee for Aeronautics. This

paper includes a detailed description of the procedure for making "pack" compressive tests. It also includes the results of tests to give a comparison of the stress-strain graphs of packs and compact solid specimens taken from the same bar of metal, and to determine the reproducibility of the test where two or more packs were taken longitudinally or transversely from sheets of 17ST aluminum alloy, No. 1025 carbon steel, and annealed chronium-molybdenum steel. An abstract of a résumé of this paper, which was presented at the Fifth International Congress for Applied Mechanics, was published in the Journal of Applied Mechanics of the American Society for Mechanical Engineers, for September 1938.

The "pack" compressive test has been found useful during the past year in determining the compressive stress-strain graphs of materials taken from thin-walled structural sections, as well as from sheet. Tests made on packs assembled from specimens taken from channels of high-strength aluminum alloy showed no evidence that the packs failed by primary instability, despite deviations from flatness in the formed material which led to the presence of small voids between the specimens of the pack.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. Code, title 50, sec. 151). The Committee is composed of fifteen members appointed by the President and serving as such without compensation. The duties of the Committee are to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution," and to "direct and conduct research and experiment in aeronautics" in such laboratories as may be placed under its direction.

Prior to the enactment of the Civil Aeronautics Act of 1938, the membership of the Committee as provided by law included two representatives each from the War and Navy Departments; one each from the Smithsonian Institution, the United States Weather Bureau, and the National Bureau of Standards; and eight other persons "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." In recent years one of these eight positions has been filled by a representative of the Bureau of Air Commerce. The Civil Aeronautics Act of 1938 provided that the Civil Aeronautics Authority therein created for the encouragement and regulation of civil and commercial aviation should have two representatives on the Committee, the same as the Army and the Navy. As the total membership remains at fifteen, the result is that the governmental members now number nine and the nongovernmental members six.

The Civil Aeronautics Act of 1938 also provided that, upon the effective date of the act (August 22, 1938) the terms of office of the nongovernmental members of the Committee should expire, and that the President should appoint successors to six, two each for periods of one, three, and five years, respectively, and thereafter for terms of five years. The provision of law referred to is Section 1107 (e) of the Civil Aeronautics Act of 1938, which reads as follows:

"The ninth paragraph of the Act approved March 3, 1915 (38 Stat. 930), as amended by the Act of March 2, 1929 (45 Stat. 1451; U. S. C., 1934 ed., title 50, sec. 151), is further amended by inserting after the words 'naval aeronautics'; in that paragraph the following: 'two members from the Civil Aeronautics Authority;', by striking out the word 'eight' in that paragraph and inserting in lieu thereof the word 'six', and by striking out the colon after the words 'allied sciences' and inserting in lieu thereof a period and the following: 'The members of the National Advisory Committee for Aeronautics, not representing governmental agencies, in office on the date of enactment of the Civil Aeronautics Act of 1938, shall continue to serve as members of the Committee until the effective date of section 1107 of the Civil Aeronautics Act of 1938. Upon the expiration of their terms of office the President is authorized to appoint successors to six of such members for terms of office to expire, as designated by the President at the time of appointment, two at the end of one year, two at the end of three years, and two at the end of five years from December 1, 1938. Successors to those first appointed shall be appointed by the President for terms of five years from the date of the expiration of the terms of the members whom they succeed, except that any such successor, appointed to fill a vacancy occurring prior to the expiration of a term, shall be appointed only for the unexpired term of the member whom he succeeds:'."

In accordance with the above provision of law, the President, under date of August 23, 1938, made the following appointments as members of the Committee:

To represent the Civil Aeronautics Authority (without definite tenure):

Honorable Edward J. Noble, Chairman, Civil Aeronautics Authority.

Honorable Clinton M. Hester, Administrator, Civil Aeronautics Authority.

For the terms expiring December 1, 1943:

Dr. Joseph S. Ames.

Dr. Orville Wright.

For the terms expiring December 1, 1941:

Dr. Edward P. Warner.

Dr. Vannevar Bush.

For the terms expiring December 1, 1939:

Colonel Charles A. Lindbergh.

Dr. Jerome C. Hunsaker.

Of the eight appointments thus made by the President, four were reappointments and four were new appointments. The four members reappointed are:

Dr. Joseph S. Ames (Chairman), President Emeritus of Johns Hopkins University, the last of the original members of the Committee appointed by the President

in 1915, who served as Chairman of the Executive Committee from 1919 to 1937, and as Chairman of the main Committee from 1927 to the present time.

Dr. Orville Wright, of Dayton, Ohio, the world's first aviator, who has served continuously since his appointment by the President in 1920.

Dr. Edward P. Warner, of Greenwich, Connecticut, former Assistant Secretary of the Navy for Aeronautics, who has served continuously since his appointment by the President in 1929, and has also served as Chairman of the Committee on Aerodynamics since 1935.

Colonel Charles A. Lindbergh, who has served continuously as a member since his appointment by the President in 1931.

The four new appointments are:

Honorable Edward J. Noble, Chairman, Civil Aeronautics Authority.

Honorable Clinton M. Hester, Administrator, Civil Aeronautics Authority.

Dr. Vannevar Bush, President, Carnegie Institution of Washington, D. C.

Dr. Jerome C. Hunsaker, Professor in Charge, The Daniel Guggenheim Aeronautical Laboratory, Massachusetts Institute of Technology.

The four members whose terms expired August 22, 1938, and who were not reappointed, are:

Honorable Harry F. Guggenheim.

Dr. William P. MacCracken.

Dr. Denis Mulligan.

Dr. David W. Taylor.

Dr. Taylor was first appointed a naval member of the Committee February 16, 1917, while serving as Chief Constructor, United States Navy, with the rank of Rear Admiral. When he retired from the Navy, he was immediately reappointed on October 16, 1922, as a member of the Committee from private life, in recognition of his outstanding ability. He was a great source of strength to the organization. His twenty-one years as a member included four years as Secretary of the Committee, eleven years as Vice Chairman of the Committee, and eight years as Chairman of the Committee on Aerodynamics.

Dr. MacCracken was Assistant Secretary of Commerce for Aeronautics when he was appointed a member of the Committee April 5, 1929, and throughout the entire period of his service he was an active and interested member. He rendered faithful and valuable service on various committees, and for six years was Chairman of the Committee on Power Plants for Aircraft. He had also served as Vice Chairman of the Executive Committee since October 21, 1937.

Mr. Guggenheim was President of the Daniel Guggenheim Fund for the Promotion of Aeronautics, Incorporated, when he was appointed a member of the Committee April 5, 1929. He brought to the Committee a well-informed and independent viewpoint on the problems of flight, which made him especially valuable as a constructive critic.

Dr. Mulligan had succeeded Dr. Fred D. Fagg, Jr., who had resigned, as Director of the Bureau of Air Commerce, and Dr. Mulligan accordingly succeeded Dr. Fagg as a member of the Committee April 16, 1938. Both Dr. Fagg and Dr. Mulligan, as successive heads of the Bureau of Air Commerce, had been thoroughly cooperative with the Committee in seeking to advance the science of aeronautics through unified control and conduct by the Committee of scientific laboratory research.

During the past year the Committee lost through death two other members, namely, Dr. Willis Ray Gregg, Chief of the United States Weather Bureau, on September 14, 1938, and Major General Oscar Westover, Chief of the Army Air Corps, on September 21, 1938.

Dr. Gregg had served as the Weather Bureau representative on the Committee since October 10, 1934, and had served as Chairman of the Executive Committee since April 22, 1937. He had given unsparingly of his time and talents to promote the effective organization and prosecution of the Committee's work.

General Westover had served as a War Department representative on the Committee since January 25, 1936. Prior to that he had become very familiar with the organization and work of the Committee, having had three previous tours of duty in the office of the Chief of the Army Air Corps since 1919 and one as Commanding Officer of Langley Field, where the Committee's laboratories are located. During this entire period he was deeply interested in the Committee's work and did much to assist this organization by promoting cooperation between the Army Air Corps and the Committee.

Major General Henry H. Arnold, who had succeeded General Westover as Chief of the Army Air Corps, was appointed a member of the Committee on October 10, 1938.

The present membership of the Committee is shown on page vi of this report. There is one vacancy on the Committee, the filling of which will await the appointment of a new Chief of the United States Weather Bureau.

Under the rules and regulations governing the work of the Committee as approved by the President, the Chairman and Vice Chairman of the Committee are elected annually. At the meeting held on October 20, 1938, Dr. Joseph S. Ames was reelected Chairman for the ensuing year, and Dr. Vannevar Bush was elected Vice Chairman to succeed Dr. David W. Taylor. At the meeting held on December 16, 1938, Dr. Vannevar Bush was elected Chairman of the Executive Committee and Dr. Charles G. Abbot Vice Chairman of the Executive Committee for the ensuing year.

The Committee's headquarters, including its offices of aeronautical intelligence and aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. Scientific and technical data on aeronautics secured from all parts of the world are classified, catalogued, and disseminated by this office.

To assist in the collection of current scientific and technical information and data, the Committee maintains a technical assistant in Europe (Mr. John J. Ide), with headquarters at the American Embassy in Paris.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the inventions section received for consideration 1,100 new submissions. It conducted the necessary correspondence and granted interviews as requested by the inventors. Approximately three percent of the new submissions were received through the Aeronautical Patents and Design Board. In those cases reports on the merits of the submissions were made to that board, and in all other cases replies were submitted directly to the inventors.

AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

The Committee has continued to follow the policy initiated as a result of recommendation of the Federal Aviation Commission, of making available a special allotment of $25,000 from each year's funds for aeronautical research in educational institutions. Under this allotment during the fiscal year 1938, contracts were made with five universities and technical schools for ten special investigations and reports, on the basis of the probable usefulness and value of the information to aeronautics.

Several of the papers prepared under contracts have been published by the Committee, and in other cases the results obtained in the investigations have supplied a basis for further research. During the past year two contract reports have been issued as Technical Notes, and four others are now being revised and edited for publication by the Committee.

COOPERATION WITH THE AVIATION INDUSTRY

In the formulation of its research programs, the Committee includes provision for the problems of aeronautical research which are of particular importance to the aviation industry, in connection with both the design and operation of aircraft. The representatives of the industry refer their problems of this nature to the Committee as they arise, either by correspondence or through personal contact. The Committee avails itself of every opportunity to obtain suggestions and recommendations from representatives of the aircraft manufacturers and operators as to investigations which are of special importance to them.

Although it was found necessary this year to postpone for one year the Aircraft Engineering Research Conference usually held each May at the Committee's laboratory at Langley Field, the Committee has continued to maintain close contact with the research needs of the industry. The conference was postponed because of the extensive program of construction of new research facilities being carried out at the laboratory, which had been undertaken by the Committee to meet the challenge offered by the great emphasis being placed by the principal foreign nations on scientific research in aeronautics, and their greatly increased research activities. As has been the long-standing policy of the Committee, when the need arises in connection with any particular problem of the industry a special conference is called, or, as previously stated, a special subcommittee is established, including in either case representation from the industry.

One of the important problems of the industry at the present time is the problem of flutter, and the Special Subcommittee on Vibration and Flutter, established under the Committee on Aerodynamics, is giving this subject special attention. It is believed that the recent results obtained by the Committee's laboratory on this subject, which are being made available in advance confidential form to American manufacturers, will be of great importance in connection with this problem. The investigation is described briefly in the report of the special subcommittee in part I.

Another problem of great importance in connection with airplane design is the aerodynamic loads imposed on the structure in flight as a result of atmospheric disturbances. As previously stated, the Committee has accumulated, with the cooperation of air-transport operators over a period of a number of years, a large amount of statistical data on these loads. These data have been obtained by means of the N. A. C. A. V–G recorder, which gives a record of accelerations and air

speeds. At the present time about 25 of these instruments are in use on American air lines, and the records obtained to date represent a total of approximately 57,000 flying hours. Further information regarding this study is presented in the report of the Committee on Aircraft Structures.

The problem of lightning hazards to aircraft has been brought to the Committee's attention by the air-transport operators, and to assist in the study of this problem a Special Subcommittee on Lightning Hazards to Aircraft has been established under the Subcommittee on Meteorological Problems, as was mentioned in the report of that subcommittee. Under the cognizance of this special subcommittee investigation is being made of the effect of electrical discharges simulating lightning strokes on sheet metal of the type used in aircraft construction. In addition, in order to obtain information as to the meteorological aspects of the problem, the air lines are supplying data from their pilots as to incidents of lightning strokes and the atmospheric conditions observed in connection with these incidents.

Realizing that frequently the value of information is greatly enhanced by its prompt availability, every effort is made to place in the hands of the industry at the earliest possible date the results of researches that are of particular interest to commercial aviation. It sometimes appears, in the course of an extensive investigation being conducted by the Committee, that the results so far obtained will be of special interest and value to the aircraft industry if made available immediately. In such cases the Committee issues the information in advance confidential form to American manufacturers and the Government services.

SUBCOMMITTEES

The Advisory Committee has organized four main standing technical committees, with subcommittees, for the purpose of supervising its work in their respective fields. The four main technical Committees on Aerodynamics, Power Plants for Aircraft, Aircraft Materials, and Aircraft Structures and their subcommittees supervise and direct the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies.

As previously stated, it is the policy of the Committee to establish from time to time special technical subcommittees for the study of particular problems as they arise. In accordance with this policy a Special Subcommittee on Vibration and Flutter has been organized under the Committee on Aerodynamics. During the past year three such special subcommittees have been formed: a Special Subcommittee on Lightning Hazards to Aircraft, under the Subcommittee on Meterological Problems; and, under the Committee on Aircraft Structures, a Special Subcommittee to Make Survey of Technique and Equipment for Elastic Examination of Large Aircraft Structures in Lieu of Destruction Tests, and a Special Subcommittee to Direct Research in Applied Structures.

The work of the standing technical committees and subcommittees has been described in part I.

The organization of the committees and of the subcommittees is as follows:

COMMITTEE ON AERODYNAMICS

Dr. Edward P. Warner, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Dr. L. J. Briggs, National Bureau of Standards.
Comdr. W. S. Diehl, United States Navy.
Dr. H. L. Dryden, National Bureau of Standards.
John Easton, Civil Aeronautics Authority.
Lt. Comdr. L. M. Grant, United States Navy.
J. T. Gray, Civil Aeronautics Authority.
Maj. Carl F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.
Delbert M. Little, United States Weather Bureau.
Maj. Alfred J. Lyon, Air Corps, United States Army, Matériel Division, Wright Field.
Elton W. Miller, National Advisory Committee for Aeronautics.
Comdr. F. W. Pennoyer, Jr., United States Navy.
H. J. E. Reid, National Advisory Committee for Aeronautics.
Maj. John P. Richter, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

SUBCOMMITTEE ON AIRSHIPS

Dr. J. C. Hunsaker, Chairman.
Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.
John Easton, Civil Aeronautics Authority.
Commander Garland Fulton, United States Navy.
Maj. C. F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Francis W. Reichelderfer, United States Weather Bureau, Chairman.
Col. E. S. Gorrell, Air Transport Association of America.
Dr. W. J. Humphreys, United States Weather Bureau.
Dr. J. C. Hunsaker, Massachusetts Institute of Technology.
R. W. Knight, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Delbert M. Little, United States Weather Bureau.
Comdr. Wilber M. Lockhart, United States Navy.
Dr. Charles F. Marvin.
Dr. C. G. Rossby, Massachusetts Institute of Technology.
Maj. B. J. Sherry, United States Army, Signal Corps, War Department.

SPECIAL SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

Delbert M. Little, United States Weather Bureau, Chairman.
J. C. Franklin, Transcontinental & Western Air, Inc.
Lt. Comdr. L. M. Grant, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
K. B. McEachron, General Electric Company.
Irving R. Metcalf, Civil Aeronautics Authority.
Lt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. F. B. Silsbee, National Bureau of Standards.
Dr. John B. Whitehead, Johns Hopkins University.

SUBCOMMITTEE ON SEAPLANES

Dr. J. C. Hunsaker, Chairman.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Comdr. W. S. Diehl, United States Navy.
J. T. Gray, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
A. L. Morse, Civil Aeronautics Authority.
Capt. H. C. Richardson, United States Navy.
Lt. Comdr. A. O. Rule, United States Navy.
Starr Truscott, National Advisory Committee for Aeronautics.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

H. J. E. Reid, National Advisory Committee for Aeronautics, Chairman.
Lt. Frederick R. Dent, Jr., Air Corps, United States Army, Matériel Division, Wright Field.
Comdr. W. S. Diehl, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.
Dr. George W. Lewis, National Advisory Committtee for Aeronautics (ex officio member).
Comdr. R. D. MacCart, United States Navy.
Irving R. Metcalf, Civil Aeronautics Authority.
Ford L. Prescott, Matériel Division, Army Air Corps, Wright Field.
Dr. Walter Ramberg, National Bureau of Standards.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Dr. Vannevar Bush, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Comdr. Rico Botta, United States Navy.
Dr. H. C. Dickinson, National Bureau of Standards.
John H. Geisse, Civil Aeronautics Authority.
Carlton Kemper, National Advisory Committtee for Aeronautics.
Gaylord W. Newton, Civil Aeronautics Authority.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Dr. H. C. Dickinson, National Bureau of Standards, Chairman.
Comdr. Rico Botta, United States Navy.
Lt. J. W. C. Brand, United States Navy.
Dr. O. C. Bridgeman, National Bureau of Standards.
H. K. Cummings, National Bureau of Standards.
L. S. Hobbs, The Pratt and Whitney Aircraft Company.
Robert V. Kerley, Matériel Division, Army Air Corps, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Gaylord W. Newton, Civil Aeronautics Authority.
Arthur Nutt, Wright Aeronautical Corporation.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.
Addison M. Rothrock, National Advisory Committee for Aeronautics.

COMMITTEE ON AIRCRAFT MATERIALS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.
S. K. Colby, Aluminum Co. of America.
Lt. Comdr. C. F. Cotton, United States Navy.
Edgar H. Dix, Jr., American Magnesium Corporation.
John Easton, Civil Aeronautics Authority.
Warren E. Emley, National Bureau of Standards.
Comdr. Garland Fulton, United States Navy.
J. T. Gray, Civil Aeronautics Authority.
C. H. Helms, National Advisory Committee for Aeronautics.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
H. S. Rawdon, National Bureau of Standards.
E. C. Smith, Republic Steel Corporation.
Paul F. Voigt, Jr., Carnegie-Illinois Steel Corporation.
Dr. Edward P. Warner.

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

H. S. Rawdon, National Bureau of Standards, Chairman.
A. W. Dallas, Civil Aeronautics Authority.
E. H. Dix, Jr., American Magnesium Corporation.
Comdr. Garland Fulton, United States Navy.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
E. C. Smith, Republic Steel Corporation.
Prof. H. L. Whittemore, National Bureau of Standards.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

Warren E. Emley, National Bureau of Standards, Chairman.
C. J. Cleary, Matériel Division, Army Air Corps, Wright Field.
A. W. Dallas, Civil Aeronautics Authority.
C. H. Helms, National Advisory Committee for Aeronautics.
E. F. Hickson, National Bureau of Standards.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
J. E. Sullivan, Bureau of Aeronautics, Navy Department.
G. W. Trayer, Forest Service, Department of Agriculture.

COMMITTEE ON AIRCRAFT STRUCTURES

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
John Easton, Civil Aeronautics Authority.
Lt. Comdr. L. M. Grant, United States Navy.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Comdr. R. D. MacCart, United States Navy.
Lt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. Walter Ramberg, National Bureau of Standards.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. L. B. Tuckerman, National Bureau of Standards.
Dr. Edward P. Warner.

SPECIAL SUBCOMMITTEE TO MAKE SURVEY OF TECHNIQUE AND EQUIPMENT FOR ELASTIC EXAMINATION OF LARGE AIRCRAFT STRUCTURES IN LIEU OF DESTRUCTION TESTS

Richard V. Rhode, National Advisory Committee for Aeronautics, Chairman.
Lt. Comdr. L. M. Grant, United States Navy.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Comdr. R. D. MacCart, United States Navy.
Irving R. Metcalf, Civil Aeronautics Authority.
R. L. Templin, Aluminum Company of America.
Dr. L. B. Tuckerman, National Bureau of Standards.

SPECIAL SUBCOMMITTEE TO DIRECT RESEARCH IN APPLIED STRUCTURES

Lt. Comdr. L. M. Grant, United States Navy, Chairman.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. L. B. Tuckerman, National Bureau of Standards.

COMMITTEE ON AIRCRAFT ACCIDENTS

Dr. Edward P. Warner, Chairman.
Lt. W. A. Evans, United States Navy.
Maj. E. V. Harbeck, Jr., Air Corps, United States Army.
J. W. Lankford, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics.
Lt. Comdr. A. O. Rule, United States Navy.
Maj. Lowell H. Smith, Air Corps, United States Army.
Grove Webster, Civil Aeronautics Authority.

COMMITTEE ON AERONAUTICAL INVENTIONS AND DESIGNS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
Hon. Clinton M. Hester, Civil Aeronautics Authority.
Dr. J. C. Hunsaker.
Capt. S. M. Kraus, United States Navy.
Brig. Gen. A. W. Robins, Air Corps, United States Army, Matériel Division, Wright Field.
John F. Victory, Secretary.

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

Dr. Joseph S. Ames, Chairman.
Dr. Charles G. Abbot.
Miss M. M. Muller, Secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, Chairman.
Dr. Vannevar Bush.
John F. Victory, Secretary.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft.

The following are lists of the publications issued:

LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

No.

612. Heat-Transfer Processes in Air-Cooled Engine Cylinders. By Benjamin Pinkel, N. A. C. A.
613. The Variation with Reynolds Number of Pressure Distribution over an Airfoil Section. By Robert M. Pinkerton, N. A. C. A.
614. Pressure Distribution over an N. A. C. A. 23012 Airfoil with an N. A. C. A. 23012 External-Airfoil Flap. By Carl J. Wenzinger, N. A. C. A.
615. Column Strength of Tubes Elastically Restrained against Rotation at the Ends. By William R. Osgood, National Bureau of Standards.
616. Interrelation of Exhaust-Gas Constituents. By Harold C. Gerrish and Fred Voss, N. A. C. A.
617. Auto-Ignition and Combustion of Diesel Fuel in a Constant-Volume Bomb. By Robert F. Selden, N. A. C. A.
618. Comparative Flight and Full-Scale Wind-Tunnel Measurements of the Maximum Lift of an Airplane. By Abe Silverstein, S. Katzoff, and James A. Hootman, N. A. C. A.
619. Drag of Cylinders of Simple Shapes. By W. F. Lindsey, N. A. C. A.
620. Pressure Distribution over Airfoils with Fowler Flaps. By Carl J. Wenzinger and Walter B. Anderson, N. A. C. A.
621. Compressible Flow about Symmetrical Joukowski Profiles. By Carl Kaplan, N. A. C. A.
622. A Photographic Study of Combustion and Knock in a Spark-Ignition Engine. By A. M. Rothrock and R. C. Spencer, N. A. C. A.
623. A Study of the Torque Equilibrium of an Autogiro Rotor. By F. J. Bailey, Jr., N. A. C. A.
624. Two-Dimensional Subsonic Compressible Flow past Elliptic Cylinders. By Carl Kaplan, N. A. C. A.
625. A Discussion of Certain Problems Connected with the Design of Hulls of Flying Boats and the Use of General Test Data. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
626. The Transition Phase in the Take-Off of an Airplane. By J. W. Wetmore, N. A. C. A.
627. The Experimental and Calculated Characteristics of 22 Tapered Wings. By Raymond F. Anderson, N. A. C. A.
628. Aerodynamic Characteristics of a Large Number of Airfoils Tested in the Variable-Density Wind Tunnel. By Robert M. Pinkerton and Harry Greenberg, N. A. C. A.

629. On Some Reciprocal Relations in the Theory of Nonstationary Flows. By I. E. Garrick, N. A. C. A.
630. A Flight Comparison of Conventional Ailerons on a Rectangular Wing and of Conventional and Floating Wing-Tip Ailerons on a Tapered Wing. By H. A. Soulé and W. Gracey, N. A. C. A.
631. Airfoil Section Characteristics as Applied to the Prediction of Air Forces and Their Distribution on Wings. By Eastman N. Jacobs and R. V. Rhode, N. A. C. A.
632. The Crinkling Strength and the Bending Strength of Round Aircraft Tubing. By William R. Osgood, National Bureau of Standards.
633. Pressure Distribution over an N. A. C. A. 23012 Airfoil with a Slotted and a Plain Flap. By Carl J. Wenzinger and James B. Delano, N. A. C. A.
634. Calculation of the Chordwise Load Distribution over Airfoil Sections with Plain, Split, or Serially Hinged Trailing-Edge Flaps. By H. Julian Allen, N. A. C. A.
635. Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist. By Henry A. Pearson and Robert T. Jones, N. A. C. A.
636. Approximate Stress Analysis of Multistringer Beams with Shear Deformation of the Flanges. By Paul Kuhn, N. A. C. A.
637. Determination of Boundary-Layer Transition on Three Symmetrical Airfoils in the N. A. C. A. Full-Scale Wind Tunnel. By Abe Silverstein and John V. Becker, N. A. C. A.
638. The Influence of Lateral Stability on Disturbed Motions of an Airplane with Special Reference to the Motions Produced by Gusts. By Robert T. Jones, N. A. C. A.
639. The Effect of Compressibility on Eight Full-Scale Propellers Operating in the Take-Off and Climbing Range. By David Biermann and Edwin P. Hartman, N. A. C. A.
640. The Aerodynamic Characteristics of Full-Scale Propellers Having 2, 3, and 4 Blades of Clark Y and R. A. F. 6 Airfoil Sections. By Edwin P. Hartman and David Biermann, N. A. C. A.
641. The Negative Thrust and Torque of Several Full-Scale Propellers and Their Application to Various Flight Problems. By Edwin P. Hartman and David Biermann, N. A. C. A.
642. Tests of Five Full-Scale Propellers in the Presence of a Radial and a Liquid-Cooled Engine Nacelle, Including Tests of Two Spinners. By David Biermann and Edwin P. Hartman.
643. The Aerodynamic Characteristics of Four Full-Scale Propellers Having Different Plan Forms. By Edwin P. Hartman and David Biermann, N. A. C. A.
644. The Torsional and Bending Deflection of Full-Scale Aluminum-Alloy Propeller Blades under Normal Operating Conditions. By Edwin P. Hartman and David Biermann.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

616. The Measurement of Air Speed of Airplanes. By F. L. Thompson, N. A. C. A.
617. Stability of Structural Members under Axial Load. By Eugene E. Lundquist, N. A. C. A.
618. Increasing the Strength of Aluminum-Alloy Columns by Prestressing. By M. Holt and E. C. Hartmann, Aluminum Research Laboratories.
619. Compression-Ignition Engine Performance at Altitudes and at Various Air Pressures and Temperatures. By Charles S. Moore and John H. Collins, N. A. C. A.
620. Energy Loss, Velocity Distribution, and Temperature Distribution for a Baffled Cylinder Model. By Maurice J. Brevoort, N. A. C. A.
621. Pressure Drop across Finned Cylinders Enclosed in a Jacket. By Vern G. Rollin and Herman H. Ellerbrock, Jr., N. A. C. A.
622. Flight Tests of an Airplane Showing Dependence of the Maximum Lift Coefficient on the Test Conditions. By H. A. Soulé and James A. Hootman, N. A. C. A.
623. Maximum Forces Applied by Pilots to Wheel-Type Controls. By William H. McAvoy, N. A. C. A.
624. Performance Characteristics of Venturi Tubes Used in Aircraft for Operating Air-Driven Gyroscopic Instruments. By Harcourt Sontag and Daniel P. Johnson, National Bureau of Standards.
625. Spinning Characteristics of Wings. IV—Changes in Stagger of Rectangular Clark Y Biplane Cellules. By M. J. Bamber and R. O. House, N. A. C. A.
626. Static Thrust Analysis of the Lifting Airscrew. By Montgomery Knight and Ralph A. Hefner, Georgia School of Technology.
627. Pressure Distribution over a Clark Y–H Airfoil Section with a Split Flap. By Carl J. Wenzinger, N. A. C. A.
628. Plastics as Structural Materials for Aircraft. By G. M. Kline, National Bureau of Standards.
629. A Sound Pressure-Level Meter without Amplification. By E. Z. Stowell, N. A. C. A.
630. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. II—Mass Distributed along the Fuselage. By Oscar Seidman and A. I. Neihouse, N. A. C. A.
631. Wind-Tunnel Tests of Carburetor-Intake Rams. By Frank H. Highley, N. A. C. A.
632. Improvement of Aileron Effectiveness by the Prevention of Air Leakage through the Hinge Gap as Determined in Flight. By H. A. Soulé and W. Gracey, N. A. C. A.
633. Spinning Characteristics of Wings. V—N. A. C. A. 0009, 23018, and 6718 Monoplane Wings. By M. J. Bamber and R. O. House, N. A. C. A.
634. The N. A. C. A. Optical Engine Indicator. By Robert E. Tozier, N. A. C. A.
635. Tank Tests of a Model of One Hull of the Savoia S–55–X Flying Boat—N. A. C. A. Model 46. By John M. Allison, N. A. C. A.
636. The Estimation of the Rate of Change of Yawing Moment with Sideslip. By Frederick H. Imlay, N. A. C. A.
637. Preliminary Fatigue Studies on Aluminum Alloy Aircraft Girders. By Goodyear-Zeppelin Corporation.
638. Tank Tests of Model 36 Flying-Boat Hull. By John M. Allison, N. A. C. A.
639. A Preliminary Investigation of Boundary-Layer Transition along a Flat Plate with Adverse Pressure Gradient. By Albert E. von Doenhoff, N. A. C. A.
640. Interference of Wing and Fuselage from Tests of 18 Combinations in the N. A. C. A. Variable-Density Tunnel—Combinations with Split Flaps. By Albert Sherman, N. A. C. A.
641. Interference of Wing and Fuselage from Tests of 17 Combinations in the N. A. C. A. Variable-Density Tunnel—Combinations with Special Junctures. By Albert Sherman, N. A. C. A.
642. Interference of Wing and Fuselage from Tests of Eight Combinations in the N. A. C. A. Variable-Density Tunnel—Combinations with Tapered Fillets and Straight-Side Junctures. By Albert Sherman, N. A. C. A.
643. A Study of Flying-Boat Take-Off. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.

644. Flight and Wind-Tunnel Tests of an XBM–1 Dive Bomber. By Philip Donely and Henry A. Pearson, N. A. C. A.
645. Some Aspects of the Stalling of Modern Low-Wing Monoplanes. By Hartley A. Soulé and Melvin N. Gough, N. A. C. A.
646. Wind-Tunnel Tests of a 2-Engine Airplane Model as a Preliminary Study of Flight Conditions Arising on the Failure of One Engine. By Edwin P. Hartman, N. A. C. A.
647. Engine Performance and Knock Rating of Fuels for High-Output Aircraft Engines. By A. M. Rothrock and Arnold E. Biermann, N. A. C. A.
648. The Increase in Frictional Resistance Caused by Various Types of Rivet Heads as Determined by Tests of Planing Surfaces. By Starr Truscott and J. B. Parkinson, N. A. C. A.
649. The Effect of Air-Passage Length on the Optimum Fin Spacing for Maximum Cooling. By Maurice J. Brevoort, N. A. C. A.
650. Wind-Tunnel Tests of a Clark Y Wing Having Split Flaps with Gaps. By Carl J. Wenzinger, N. A. C. A.
651. Effect of Spark-Timing Regularity on the Knock Limitations of Engine Performance. By Arnold E. Biermann, N. A. C. A.
652. Tables of Stiffness and Carry-Over Factor for Structural Members under Axial Load. By Eugene E. Lindquist and W. D. Kroll, N. A. C. A.
653. A Flight Investigation of the Reduction of Aileron Operating Force by Means of Fixed Tabs and Differential Linkage, with Notes on Linkage Design. By H. A. Soulé and James A. Hootman, N. A. C. A.
654. Fuel Consumption of a Carburetor Engine at Various Speeds and Torques. By Oscar W. Schey and J. Denny Clark, N. A. C. A.
655. Principles Involved in the Cooling of a Finned and Baffled Cylinder. By M. J. Brevoort, N. A. C. A.
656. Hydrodynamic and Aerodynamic Tests of Models of Floats for Single-Float Seaplanes—N. A. C. A. Models 41–D, 41–E, 61–A, 73, and 73–A. By J. B. Parkinson and R. O. House, N. A. C. A.
657. Tank Tests to Show the Effect of Rivet Heads on the Water Performance of a Seaplane Float. By J. B. Parkinson, N. A. C. A.
658. Generalized Analysis of Experimental Observations in Problems of Elastic Stability. By Eugene E. Lundquist, N. A. C. A.
659. Wind-Tunnel Tests of Three Lateral-Control Devices in Combination with a Full-Span Slotted Flap on an N. A. C. A. 23012 Airfoil. By Carl J. Wenzinger and Millard J. Bamber, N. A. C. A.
660. Fatigue Testing of Wing Beams by the Resonance Method. By William M. Bleakney, National Bureau of Standards.
661. Wind-Tunnel Investigation of Rectangular and Tapered N. A. C. A. 23012 Wings with Plain Ailerons and Full-Span Split Flaps. By Carl J. Wenzinger and Milton B. Ames, Jr., N. A. C. A.
662. Gyroscopic Instruments for Instrument Flying. By W. G. Brombacher and W. C. Trent, National Bureau of Standards.
663. The Effects of Partial-Span Plain Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered Clark Y Wing. By R. O. House, N. A. C. A.
664. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. III—Mass Distributed along the Wings. By Oscar Seidman and A. I. Neihouse, N. A. C. A.
665. Tests of N–85, N–86, and N–87 Airfoil Sections in the 11-Inch High-Speed Wind Tunnel. By John Stack and W. F. Lindsey, N. A. C. A.
666. Longitudinal Stability in Relation to the Use of an Automatic Pilot. By Alexander Klemin, Perry A. Pepper, and Howard A. Wittner, New York University.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

839. The Design of Airplane Engine Superchargers. By Werner von der Nüll. From Luftfahrtforschung, April 20, 1937.
840. Research and Design Problems Introduced by Increased Power Output. By Oskar Kurtz. From Luftwissen, April 1937.
841. Synthetic Resins in Aircraft Construction—Their Composition, Properties, Present State of Development and Application to Light Structures. By K. Riechers. From Luftwissen, August 1937.
842. Universal Logarithmic Law of Velocity Distribution as Applied to the Investigation of Boundary Layer and Drag of Streamline Bodies at Large Reynolds Number. By G. Gurjienko. From Report No. 257 of the Central Aero-Hydrodynamical Institute, Moscow, 1936.
843. Detonation and Autoignition. Some Considerations on Methods of Determination. By G. D. Boerlage. From Journees Techniques Internationales de L'Aeronautique, November 23–27, 1936.
844. Flow in Smooth Straight Pipes at Velocities above and below Sound Velocity. By W. Frössel. From Forschung auf dem Gebiete des Ingenieurwesens, March–April 1936.
845. On the Theory of Hydrofoils and Planing Surfaces. By F. Weinig. From Luftfahrtforschung, June 20, 1937.
846. The Buckling of Curved Tension-Field Girders. By G. Limpert. From Luftfahrtforschung, July 20, 1937.
847. Stresses in Reinforcing Rings Due to Axial Forces in Cylindrical and Conical Stressed Skins. By K. Drescher and H. Gropler. From Luftfahrtforschung, February 20, 1937.
848. Planing-Surface Tests at Large Froude Numbers—Airfoil Comparison. By A. Sambraus. From Luftfahrtforschung, August 20, 1936.
849. Rate-of-Climb Recorder. By Helmut Danielzig. From Luftwissen, May 1937.
850. Engines and Propellers for Powered Gliders and Light Airplanes. By H. Gropp. From Flugsport, November 24, 1937.
851. Twisting Failure of Centrally Loaded Open-Section Columns in the Elastic Range. By Robert Kappus. From Luftfahrtforschung, September 20, 1937.
852. Systematic Airfoil Tests in the Large Wind Tunnel of the DVL. By H. Doetsch and M. Kramer. From Luftfahrtforschung, October 12, 1937.
853. Effect of Air-Fuel Ratio on Detonation in Gasoline Engines. By L. A. Peletier. From Second World Petroleum Congress, Paris, June 1937.
854. Twisting of Thin-Walled Columns Perfectly Restrained at One End. By Lucio Lazzarino. From L'Aerotecnica, October 1937.
855. Model Experiments on the Forces and Moments on an End Plate Fitted to a Wing. By O. Schrenk. From Luftfahrtforschung, November 20, 1937.
856. The Lift Distribution of Wings with End Plates. By W. Mangler. From Luftfahrtforschung, November 20, 1937.

857. Investigation of Ignition and Combustion Processes of Diesel Engines Operating with Turbulence and Air-Storage Chambers. By Hans Petersen. From Forschung auf dem Gebiete des Ingenieurwesens, November–December 1937.
858. The Focke Helicopter. By H. Focke. From Luftwissen, February 1938.
859. A New Spinning-Test Method. By M. Kramer and K. B. Krüger. From Luftfahrtforschung, October 12, 1937.
860. The Design of Floats. By W. Sottorf. From Luftfahrtforschung, April 20, 1937.
861. Compression Struts with Nonprogressively Variable Moment of Inertia. By B. Radomski. From Luftfahrtforschung, September 20, 1937.
862. The Influence of Notches under Static Stress. By K. Matthaes. From Luftfahrtforschung, January 20, 1938.
863. On the Determination of the Take-Off Characteristics of a Seaplane. By A. Perelmuter. From Report No. 255, Central Aero-Hydrodynamical Institute, Moscow, 1936.
864. Load Tests on a Stiffened Circular Cylindrical Shell. By E. Schapitz and G. Krümling. From Luftfahrtforschung, December 20, 1937.
865. Behavior of Static Pressure Heads at High Speeds. By Helmut Danielzig. From Luftfahrtforschung, June 20, 1937.
866. Calculation of Load Distribution in Stiffened Cylindrical Shells. By H. Ebner and H. Köller. From Luftfahrtforschung, December 20, 1937.
867. Theoretical Study of Various Airplane Motions after Initial Disturbance. By Fr. Haus. From Bulletin du Service Technique de L'Aeronautique, No. 17, June 1937.
868. The Dornier Wind Tunnel. By H. Schlichting. From Luftfahrtforschung, March 20, 1938.
869. The Conversion of Energy in a Radiator. By A. Weise. From Gesammelte Vorträge der Hauptversammlung 1937 der Lilienthal-Gesellschaft für Luftfahrtforschung vorgetragen in München vom 12–14, October 1937.
870. Behavior of a Plate Strip under Shear and Compressive Stresses beyond the Buckling Limit. By A. Kromm and K. Marguerre. From Luftfahrtforschung, December 20, 1937.
871. Performance of Rotating-Wing Aircraft. By K. Hohenemser. From Ingenieur-Archiv, December 1937.
872. The Present Status of Airship Construction, Especially of Airship-Framing Construction. By Hans Ebner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 6 and June 28, 1933.
873. Experimental Study of Ignition by Hot Spot in Internal Combustion Engines. By Max Serruys. From Publications Scientifiques et Techniques du Ministere de L'Air, No. 115, 1937.
874. Effect of Propeller Slipstream on Wing and Tail. By J. Stüper. From Luftfahrtforschung, April 6, 1938.
875. Heat-Stressed Structural Components in Combustion-Engine Design. By Otto Kraemer. From Zeitschrift des Vereines deutscher Ingenieure, March 12, 1938.
876. Investigations on the Downwash behind a Tapered Wing with Fuselage and Propeller. By H. Muttray. From Luftfahrtforschung, March 20, 1938.
877. Wind-Tunnel Investigations on Flexural-Torsional Wing Flutter. By H. Voigt. From Luftfahrtforschung, September 20, 1937.

AIRCRAFT CIRCULAR ISSUED DURING THE PAST YEAR

No.
209. Fairey "Battle" Medium Bomber Airplane (British). An All-Metal Low-Wing Cantilever Monoplane. From The Aeroplane, June 16 and August 18, 1937.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1938, as contained in the Independent Offices Appropriation Act approved June 28, 1937, was $1,259,850. A supplemental appropriation of $453,000 was made available in the Second Deficiency Appropriation Act, fiscal year 1937, approved May 28, 1937, for the same purposes specified in the Committee's regular appropriation act for 1937, to continue available until June 30, 1938, and providing that $353,000 should be available only for the construction and equipment of facilities and for the purchase of an airplane of the light metal private type; and providing further, that the unexpended balance of the supplemental appropriation of $1,367,000 for 1937 be continued available until June 30, 1938. That unexpended balance was $206,071. The total amount available for expenditure during the fiscal year 1938, therefore, was $1,918,921. The amount expended and obligated was $1,918,868, itemized as follows:

Personal services	$987,571
Supplies and materials	118,162
Communication service	3,037
Travel expenses	13,454
Transportation of things	3,509
Furnishing of electricity	39,828
Repairs and alterations	28,625
Special investigations and reports	92,671
Equipment	255,049
Structures	376,962
Expended and obligated	1,918,868
Unobligated balance	53
Total, general appropriation	1,918,921

The appropriation for printing and binding for 1938 was $21,000, of which $20,987 was expended.

The sum of $7,786 was received during the fiscal year 1938 as special deposits to cover the estimated cost of scientific services to be furnished private parties. The total cost of investigations completed for private parties during the fiscal year, amounting to $4,940, was deposited in the Treasury to the credit of Miscellaneous Receipts. The sum of $7,184 remained in special deposits on account of tests started during the fiscal year 1937 and unfinished as at June 30, 1937. The cost of these investigations, which were completed during fiscal year 1938, amounting to $6,178, was also deposited in the Treasury to the credit of Miscellaneous Receipts, making a total of $11,118 so deposited during the fiscal year 1938.

An allotment of $250 was received from the State Department for payments during the fiscal year 1938 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies. Of this amount $144 was paid during the fiscal year 1938 to employees of the Committee stationed in the Paris

Office, leaving a balance of $106 which was turned back into the Treasury.

Of the allotment of $2,000 for participation in the Greater Texas and Pan American Exposition at Dallas, which closed October 31, 1937, the amount of $1,995 was expended and the unobligated balance of $5 was returned to the original appropriation.

CONCLUDING STATEMENT

Air power at the present time is a dominant factor in the strength of a nation and in enabling it to maintain its independent existence and territorial integrity. Accepted theories of warfare give a steadily increasing place to air power.

Air power is primarily dependent not only upon numbers of airplanes, but the airplanes themselves must have performance at least equal to that of an enemy. The fact that modern military aircraft require frequent replacement by improved types brings forcibly to our attention the necessity of basing their design upon the best and most reliable data from research laboratories. New information is being obtained in the aeronautical laboratories of many nations, and unless our own laboratories keep pace, the United States cannot hope to compete with foreign nations in the development of either military or commercial aircraft.

The relation of laboratory research to the development of efficient aircraft is being increasingly appreciated by the world powers. The United States for a number of years has held undisputed leadership in the field of aeronautical research. At the present time that leadership is being challenged. Unless, therefore, we fully recognize the challenge and make provision for extending the Committee's research facilities and for increasing the number of its trained research personnel, the United States will definitely fall behind.

The struggle of nations to extend their influence to other countries, is resulting in determined efforts to establish air trade routes. A few years ago, great disances were an insuperable barrier to transoceanic air transportation, but the rapid improvement of aircraft has shrunk the map of the world.

Looking to the future, the progressive nations are making sacrifices and expending their national energies and resources for the purpose of advancing their air commerce. The United States, in extending and developing its domestic and international air commerce, is confronted with serious competition in the operation of air lines over the Atlantic and Pacific Oceans and to South America. In this connection the importance of scientific research cannot be overemphasized, as the long distances of flight over water demand a maximum of efficiency in aircraft. The United States leads at the present time in domestic and international air commerce. It should cherish this position and bend every effort to extend further its commercial air transportation.

The establishment of the Civil Aeronautics Authority has improved governmental aeronautical organization. The governmental agencies concerned with aeronautics are now organized on a sound and logical basis and function in cooperation. The aircraft manufacturing and operating industries have shown a commendable spirit of cooperation with the Government and with each other, and are alert to apply the results of the Committee's researches in a constant effort to improve the performance, efficiency, and safety of both military and civil aircraft. The Committee believes that the continuous and systematic conduct of scientific laboratory research on the basic problems of flight is the most fundamental activity of the Government in connection with the development of aeronautics. The Army, Navy, and Civil Aeronautics Authority are equally represented on the Committee. With their hearty cooperation the Committee coordinates the research needs of military, naval, and commercial aviation, and conducts the more fundamental scientific investigations in one central Government laboratory at Langley Field, Va. In this way a maximum of progress is obtained at minimum expense without overlapping or duplication.

In the rapidly advancing science of aeronautics the technical development of aircraft is directly dependent upon scientific laboratory research. The recent great expansion of research facilities by other nations will bring to an end the period of American leadership in the technical development of aircraft unless the United States also constructs additional research facilities. This subject is being studied by a special committee which includes in its membership the heads of the Army Air Corps, the Navy Bureau of Aeronautics, and the Civil Aeronautics Authority. The recommendations of that special committee will probably become the subject of a special report to the President and the Congress.

The Committee is grateful to the President and the Congress for the support accorded its work in the fields of basic and applied research in aeronautics. The Committee is determined to make every effort to meet its responsibilities by providing the scientific foundation for keeping America first in the technical development of both military and commercial aircraft.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman.*

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Twenty-fifth Annual Report

of the

National Advisory Committee for Aeronautics

1939

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

TWENTY-FIFTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1939

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

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WASHINGTON: 1939

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LETTER OF TRANSMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Twenty-fifth Annual Report of the Committee covering the fiscal year ended June 30, 1939.

Franklin D. Roosevelt.

The White House,
January 8, 1940.

G 629 Nat. adv. v. 25, 1939

LETTER OF SUBMITTAL

National Advisory Committee for Aeronautics,
Washington, D. C., December 21, 1939.

Mr. President:

In compliance with the provisions of the Act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to submit herewith the Twenty-fifth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1939.

The Committee is proceeding with the design and construction at Moffett Field, California, of a second major aeronautical research station authorized by Act approved August 9, 1939. This will materially augment and strengthen the Committee's facilities for research in aerodynamics.

Attention is invited to the report of the Special Survey Committee on Aeronautical Research Facilities which appears on page two. In furtherance of its recommendations, a Special Committee on Engine Research Facilities is now studying costs and preparing detailed plans for an additional engine research laboratory.

Respectfully submitted.

Vannevar Bush, *Chairman.*

The President,
The White House, Washington, D. C.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

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Washington, D. C.

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Chief Matériel Division, Air Corps, Wright Field, Dayton, Ohio.

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Director, National Bureau of Standards.

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Administrator, Civil Aeronautics Authority.

ROBERT H. HINCKLEY, A. B.,
Chairman, Civil Aeronautics Authority.

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Cambridge, Mass.

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Bureau of Aeronautics, Navy Department.

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Chief, United States Weather Bureau.

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GEORGE W. LEWIS, *Director of Aeronautical Research*

JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer-in-Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

JOHN J. IDE, *Technical Assistant in Europe, Paris, France*

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POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS
AIRCRAFT STRUCTURES
AIRCRAFT ACCIDENTS
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Preparation of Research Programs

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JOSEPH S. AMES.

PAST CHAIRMAN, NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

MEETING, OCTOBER 19, 1939.

Left to right: Brig. Gen. George H. Brett, Army Air Corps; Clinton M. Hester, Administrator, Civil Aeronautics Authority; Rear Adm. John H. Towers, Chief, Bureau of Aeronautics, Navy Department; Dr. L. J. Briggs, Director, Bureau of Standards; Col. Charles A. Lindbergh; Dr. Orville Wright; Dr. J. C. Hunsaker; Dr. George W. Lewis, Director of Aeronautical Research; Dr. Vannevar Bush, Chairman; Dr. George J. Mead, Vice Chairman; John F. Victory, Secretary; Dr. Charles G. Abbot, Secretary, Smithsonian Institution; Dr. Edward P. Warner; Maj. Gen. Henry H. Arnold, Chief, Army Air Corps; Robert H. Hinckley, Chairman, Civil Aeronautics Authority; Capt. S. M. Kraus, U. S. N.; Dr. F. W. Reichelderfer, Chief, United States Weather Bureau.

TWENTY-FIFTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 16, 1939.*

TO THE CONGRESS OF THE UNITED STATES:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151), which established the National Advisory Committee for Aeronautics, The Committee submits herewith its Twenty-Fifth Annual Report for the fiscal year 1939.

The most significant event of the past year, in its relation to the future of American aeronautics, was the authorization of a second major aeronautical research station for the Committee. This was recommended by the President in February 1939 and was authorized by the Congress in the Third Deficiency Act approved August 9, 1939. The site finally selected by the Committee under authority of that act is Moffett Field, Calif., located about 38 miles south of San Francisco. The details of this important action are set forth in part II of this report. This additional laboratory will serve to relieve the present congestion of work at the Committee's Langley Field laboratory in Virginia and will provide new research facilities necessary to enable the Committee to provide more effectively for an enlarged volume of research work to support and accelerate the technical development of American aircraft.

During the past year important progress was made in many ways in providing, through the Committee's researches at Langley Field, new knowledge which should be the basis of extensive improvements in our aircraft. Discovery during the past year of a new principle in airplane-wing design may prove of great importance. The transition from laminar to turbulent air flow over a wing was so delayed as to reduce the profile drag, or basic air resistance, by approximately two-thirds. It is too early to appraise adequately the significance of this achievement. So far, its application is limited to small airplanes, but there are indications of its ultimate applicability to larger airplanes through continued research. It should increase the range and greatly improve the economy of airplane operation.

This country's opportunity.—The advance of commercial aviation during the past few years has been remarkable. The United States is a country of great expanse, with widely separated centers of population and business activity that will require and support a much larger domestic air transportation system than now exists. Increased economy and reduced dependency upon financial aid from the Government, where such aid still exists, depend on technical progress and improvement in the inherent characteristics of the aircraft used.

The United States was the first to establish regular commercial air transport service over the North Atlantic and the Pacific Oceans. Recent progress in the attainment of a high degree of safety in air transportation is most gratifying in this connection. The long distances between the United States and Alaska, and between the United States and the South American Republics, require faster and more efficient air transportation. The development of commercial transport airplanes of ever-increasing efficiency and safety can be accelerated by investigations in our research laboratories.

Unprecedented expansion of air power.—From the standpoint of national defense, the United States is most fortunately situated between two great oceans. However, as advances in aeronautical science result in increased range of aircraft the significance of these oceans will gradually diminish and superiority in aircraft design will become more and more essential to our national safety. The year 1939, prior to the outbreak of the European War, was notable as witnessing unprecedented expansion of air power in many nations. Germany has concentrated much of its scientific and industrial resources on the problem of gaining supremacy in the air. England and France are making every effort in the same direction. Research facilities have been greatly expanded in all the major nations.

Relation of aeronautical research to national defense.—The effectiveness of an air force is largely dependent on constant activity in research laboratories necessary to

insure continuous improvement in design and performance of aircraft. Orderly prosecution of comprehensive programs of scientific research is indispensable. It is the function of the National Advisory Committee for Aeronautics to "supervise and direct the scientific study of the problems of flight with a view to their practical solution," and to "direct and conduct research and experiment in aeronautics" in such laboratories as may be placed under its direction. The Committee has for many years exercised these functions, by the direct conduct of research in its own laboratories and also by contractual relations with independent laboratories.

To coordinate the research needs of aviation, civil and military, and to prepare programs of research in the various branches of science affecting aeronautics, the Committee has established four major standing technical subcommittees, on aerodynamics, power plants for aircraft, materials for aircraft, and aircraft structures. There are also other special and subordinate subcommittees. The subcommittees are composed in part of specially qualified representatives of the governmental agencies concerned. The main committee, upon recommendations of subcommittees or upon its own initiative, authorizes research programs. The results of researches are either published or kept secret or confidential, as may be advisable in the national interest, but they are always brought promptly to the attention of the proper parties in the Government and in cooperating industry.

Enlarged plan for coordination.—The Committee, in order to exercise more fully its functions, has adopted a program of coordination of research as recommended by a special committee appointed to study that subject. The coordination of research entails for the Committee the duty of maintaining close liaison with all organizations, governmental and private, that operate research facilities. This is for the purpose of providing for the utilization, to the maximum advantage of the United States, of available research facilities in the pursuit of a coordinated program.

The Committee is cooperating with the War and Navy Departments, the Civil Aeronautics Authority, and other agencies of the Government to the fullest extent, to the end that the new facilities now being provided by the Committee and by other governmental agencies shall be of the maximum scope that can be provided with the funds available, and of proper balance as to character.

Necessary expansion of research.—The year 1940 will mark the twenty-fifth anniversary of the Committee's establishment. As the Committee reviews the effects of scientific research on the progress of aeronautics during the last quarter of a century, it is convinced that the systematic conduct of scientific research is the most fundamental activity of the Government in connection with the development of aeronautics. The Committee is gratified to have had the confidence and support of the President and of the Congress in the past. The years that lie immediately ahead will be critical years in the development of aeronautics. The Committee's work will need to be carried out on an even broader front and on a larger scale in the immediate future.

Because of the increasing relative importance of aeronautics in national defense and in transportation, the Committee believes that the needs of the country justify a further immediate expansion of research activities in two directions, namely, the establishment of an engine research laboratory, and additional stimulation of aeronautical research in educational and scientfic institutions.

With Colonel Charles A. Lindbergh as chairman, Major General Henry H. Arnold, Chief of the Army Air Corps, Rear Admiral John H. Towers, Chief of the Bureau of Aeronautics, Navy Department, and Honorable Robert H. Hinckley, Chairman of the Civil Aeronautics Authority, have served as a Special Survey Committee on Aeronautical Research Facilities. That committee, under date of October 19, 1939, submitted a report to the National Advisory Committee for Aeronautics as follows:

REPORT OF THE SPECIAL SURVEY COMMITTEE ON AERONAUTICAL RESEARCH FACILITIES

In accordance with the directions to this special committee to "examine into the aeronautical research facilities now available in the country and their best interrelationship, and to prepare a comprehensive plan for the future extension of such facilities, with especial attention to facilities of the N. A. C. A. and the universities," the following report is submitted, supplementing the committee's previous reports.

As a result of its studies, this committee finds that there is a serious lack of engine research facilities in the United States, and that it is of the utmost importance for the development of aviation in general, and for our defense porgram in particular, to take immediate steps to remedy this deficiency.

This committee, therefore, urgently recommends that an engine research laboratory be constructed at the earliest possible date, in a location easily accessible to the aircraft-engine industry.

In making this recommendation, the committee wishes to call attention to the fact that the reason for foreign leadership in certain important types of military aircraft is due in part to the superiority of foreign liquid-cooled engines. At the present time, American facilities for research on aircraft power plants are inadequate and cannot be compared with the facilities for research in other major fields of aviation.

This committee also recommends that an investigation be made of the engine research facilities which may be available at universities and other scientific organizations, with a view to coordinating these facilities and encouraging their most effective use. The committee is more than ever impressed with the desirability of using to the fullest possible extent the research facilities available in universities and other scientific organizations. The committee believes that the proper use and coordination of these facilities is one of the most

important functions that can be carried on by the National Advisory Committee for Aeronautics.

The foregoing report was unanimously approved at a full meeting of the National Advisory Committee for Aeronautics. To start action on the first recommendation, a Special Committee on Engine Research Facilities was immediately organized under the chairmanship of Dr. George J. Mead, Vice Chairman of the main Committee, and instructed to submit to the main committee a final report with detailed plans.

The Committee had anticipated the second recommendation by including in its regular estimate for the ensuing year an additional amount for research in educational and scientific institutions. This is enlarging the procedure which the Committee has followed since its beginning. In recent years the facilities of educational institutions for conducting research in aeronautics have increased and there is now an opportunity for much greater effectiveness in accelerating progress by substantially enlarging the Committee's employment of these facilities. The Committee cannot too strongly urge the importance of the proposed appropriation, for not only will it yield direct results in the form of new contributions to knowledge along a variety of lines for which the facilities and personnel of such institutions are well adapted, but it will also result in the training of research workers in aeronautics for the benefit alike of the governmental services and of the industry.

Quite as important as liberal appropriations for any aeronautical purpose is the adoption of a farsighted policy to develop trained technical personnel. The Committee believes that the stimulation of aeronautical research in scientific and educational institutions, as proposed, is the most effective and, incidentally, the most economical way to develop in larger numbers and in a democratic manner the talented individuals having the scientific training necessary to engage successfully in what has become an international competition.

Resignation of Dr. Joseph S. Ames, Chairman.—On October 7, 1939, Dr. Joseph S. Ames resigned as member and Chairman of the National Advisory Committee for Aeronautics, because his physical condition would not permit him to "take a sufficiently active part in the great work that confronts the Committee."

Dr. Ames was the last of the original members of the Committee appointed by President Wilson in 1915. He had been reappointed in 1938 by President Roosevelt for a 5-year term. For 17 years he was Chairman of the Executive Committee (1919–36), and for 12 years he was Chairman of the main Committee (1927–39). His long service included 8 years as Chairman of the Committee on Aerodynamics (1919–27) and the chairmanship of other important subcommittees, and also of the annual engineering research conferences with the aircraft industry, and of the special conferences on nomenclature for aeronautics held in 1920, 1922, 1925, and 1933. In 1923, he delivered the Wilbur Wright Memorial lecture before the Royal Aeronautical Society of Great Britain on the subject, "The Relation Between Aeronautical Research and Aircraft Design."

In 1935 Dr. Ames was awarded the Langley Gold Medal by the Board of Regents of the Smithsonian Institution "in recognition of the surpassing improvement of the performance, efficiency, and safety of American aircraft resulting from fundamental scientific researches conducted by the National Advisory Committee for Aeronautics under the leadership of Dr. Ames."

Dr. Ames, while serving as professor of physics and later as president of the Johns Hopkins University at Baltimore, Md., had devoted himself unsparingly to the work of the Committee without compensation or thought of reward. The President of the United States, in accepting his resignation on October 10, 1939, wrote as follows:

THE WHITE HOUSE,
Washington, October 10, 1939.

DR. JOSEPH S. AMES,
Guilford, Baltimore, Md.

MY DEAR DR. AMES: It is with sincere regret that I accept your resignation as a member of the National Advisory Committee for Aeronautics, submitted because of your physical inability to take an active part in the Committee's work at this critical time.

Our Republic would not be worthy of the devoted service you have rendered for over 24 years without compensation if it could not on this occasion pause to pay tribute where it is so justly due.

When you were first appointed by President Wilson in 1915, very little was known about the science of aeronautics. To you and to your colleagues were entrusted by law the supervision and direction of the scientific study of the problems of flight. For the past 20 years you have served as Chairman of the National Advisory Committee for Aeronautics, or Chairman of its Executive Committee. The administration and the accomplishments of the Committee under your leadership reflect your great scientific attainments, professional courage, and executive ability.

That the people generally have not known of your brilliant and patriotic service is because it has been overshadowed by your passion for accomplishment without publicity. But the fact remains, and I am happy to give you credit for it, that the remarkable progress for many years in the improvement of the performance, efficiency, and safety of American aircraft, both military and commercial, has been due largely to your own inspiring leadership in the development of new research facilities and in the orderly prosecution of comprehensive research programs.

I wish you many years of peace and contentment in which to enjoy the satisfaction that should be yours as you view the continuing results of your labors.

Very sincerely yours,

FRANKLIN D. ROOSEVELT.

The limitations of a public document preclude the presentation of a full account of Dr. Ames' contribu-

tions to the advancement of the science of aeronautics. In view of his outstanding record of public service, it is deemed appropriate to publish the fact that at a full meeting of the National Advisory Committee for Aeronautics held in Washington, D. C., on October 19, 1939, at which the resignation of Dr. Ames was announced, by unanimous rising vote of the members, the following testimonial to Dr. Ames was adopted:

Resolved, That the members of the National Advisory Committee for Aeronautics do adopt and approve the following tribute to their distinguished past Chairman:

For over 20 years Dr. Ames has served as Chairman of the National Advisory Committee for Aeronautics or as chairman of its executive committee. His long service leaves upon the organization the indelible imprint of his character. He is not only a great scientist, he is a great man, and we are proud to have been associated with him.

When aeronautical science was struggling to discover its fundamentals, his was the vision that saw the need for novel research facilities and for organized and sustained prosecution of scientific laboratory research. His was the professional courage that led the Committee along new scientific paths to important discoveries and contributions to progress that have placed the United States in the forefront of progressive nations in the development of aeronautics. His was the executive ability and farsighted policy of public service that, without seeking credit for himself or for the Committee, developed a research organization that holds the confidence of the governmental and industrial agencies concerned and commands the respect of the aeronautical world. Withal, Dr. Ames was an inspiring leader of men and a man beloved by all his colleagues because of his rare personal qualities.

Dr. Ames' retirement from active duty because of his physical inability to carry on is sincerely regretted by all who know of his unparalleled service to American aeronautics.

Resolved further, That the Chairman be authorized to appoint a special committee to present this testimonial to Dr. Ames with our heartfelt thanks for all that he has done for the Committee and with our sincere wishes that he may be spared for many years to witness in peace and contentment the continuing fruits of his labors.

The foregoing testimonial to Dr. Ames was engrossed and signed by all the members of the Committee. It was presented to Dr. Ames at his residence in Baltimore on October 23 by a special committee composed of Dr. Edward Warner, Chairman; Dr. Vannevar Bush, Dr. Lyman J. Briggs, Dr. George W. Lewis, and Mr. John F. Victory. Dr. Warner made the presentation with appropriate expression of the great admiration and esteem in which Dr. Ames is held by all members of the Committee.

Recommendations.—The Committee urgently recommends that it be authorized to construct an engine research laboratory at the earliest possible date in a location easily accessible to the aircraft-engine industry. The Special Survey Committee on Aeronautical Research Facilities, as a result of its studies, found "that there is a serious lack of engine research facilities and that it is of the utmost importance for the development of aviation in general, and for our defense program in particular, to take immediate steps to remedy this deficiency." That special committee called attention to the fact that the reason for foreign leadership in certain important types of military aircraft is due in part to the superiority of foreign liquid-cooled engines, and added that "at the present time American facilities for research on aircraft power plants are inadequate and cannot be compared with the facilities for research in other major fields of aviation." Detail studies are being made by the Special Committee on Engine Research Facilities, which will probably develop plans for the construction of an engine research laboratory on a site to be selected by the Committee.

The Committee's regular estimates of appropriations for the fiscal year 1941 include an increased appropriation for the stimulation of aeronautical research in scientific and educational institutions by contracting for research in these institutions supplementing research in Government laboratories. It is strongly recommended that this be approved.

PART I

REPORTS OF TECHNICAL COMMITTEES

In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These technical committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various governmental agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication.

In addition to its standing committees and subcommittees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The Committee has four principal technical committees—the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, the Committee on Aircraft Materials, and the Committee on Aircraft Structures. Under these committees there are six standing subcommittees. The membership of these technical committees and subcommittees is listed in part II.

The Committees on Aerodynamics and Power Plants for Aircraft prepare the programs for, and keep in touch with, the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the National Bureau of Standards. Most of the research under the cognizance of the Committee on Aircraft Materials is conducted by the National Bureau of Standards. A large part of the research under the cognizance of the Committee on Aircraft Structures is carried on by the National Bureau of Standards. In addition, a number of structural investigations, including in particular investigations of a theoretical nature, are conducted at the Committee's laboratory at Langley Field and at educational institutions.

The four technical committees recommend to the main Committee the investigations in their respective fields to be undertaken by educational institutions under contract with the National Advisory Committee for Aeronautics, and keep in touch with the progress of the work and the results obtained. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and aircraft structures undertaken by the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and other Government agencies are reported to these four committees.

REPORT OF COMMITTEE ON AERODYNAMICS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANDING SPEED AND SPEED RANGE

The emphasis now being placed on the high-speed performance of military airplanes is resulting in marked increases in wing loadings and is creating a strong demand for improved high-lift devices. To meet this demand, the committee has been devoting increasing effort to the investigation of the more promising types of partial- and full-span flaps.

The investigation of wings with slotted flaps in the 7- by 10-foot wind tunnel has been extended to include airfoils having thickness ratios of 21 and 30 percent. For the airfoil of 21-percent thickness (Technical Report No. 677), the maximum lift coefficient obtained with the best slotted flap was about the same as for the airfoil of 12-percent thickness (Technical Report No. 664). With the 30-percent-thick airfoil, however, the maximum lift coefficient obtained was about 10 percent less with the best slotted flap than for the thinner airfoils. The drag for a given lift coefficient increased with airfoil thickness; therefore, the best speed-range ratio was obtained with the thinnest airfoil. The investigation has also been extended to cover wide-chord slotted flaps on airfoils of the three thicknesses. Results of tests of the N. A. C. A. 23012 and 23021 airfoils with 40-percent-chord flap (Technical Notes Nos. 715 and 728) showed no appreciable gain in maximum lift coefficient over the 25-percent-chord flap. The thicker airfoil had a considerably higher drag coefficient.

The results of an investigation in the 7- by 10-foot wind tunnel of a multiple-flap arrangement mentioned

in the last annual report have been published as Technical Report No. 679. The investigation of double-slotted flaps has been extended to flaps of wider chord and to airfoils of different thicknesses.

Tests have been made in the 7- by 10-foot wind tunnel on a rectangular and a tapered N. A. C. A. 23012 wing with partial-span slotted flaps. The results of these tests, published in Technical Note No. 719, are similar to the results on the partial-span plain and split flaps previously reported; greater increments of maximum lift were obtained with the slotted flaps.

An investigation has been made (Technical Note No. 699) in the 7- by 10-foot wind tunnel on a slotted deflector-plate flap on an N. A. C. A. 23012 airfoil. This flap gave on this airfoil a somewhat lower maximum lift coefficient than the best slotted flap of the same chord.

Tests have also been made in the 7- by 10-foot wind tunnel of split flaps of 10-, 20-, 30-, and 40-percent chord on N. A. C. A. 23012, 23021, and 23030 airfoils. The results of these tests have been published in Technical Report No. 668. It was found that the final maximum lift coefficients for the three airfoils with 20-percent-chord flaps were equal; for airfoils with 10-percent-chord flaps the maximum lift coefficient decreased with airfoil thickness; and for the flaps of 30- and 40-percent chord, the maximum lift coefficient increased with airfoil thickness.

Data dealing with the air loads on flaps and slats have been collected from various sources, correlated, and published as Technical Note No. 690.

CONTROL AND CONTROLLABILITY

Variation of control effectiveness with airplane size.—During the past year investigations of the flying qualities of a number of airplanes, ranging in weight from 4,500 to 70,000 pounds, have provided considerable data on the variation of control effectiveness with airplane size. With regard to the aileron control, the reduction in effectiveness with increased wing span, as indicated by the maximum rolling velocity, was found to be greatly in excess of that indicated by the theoretical relationship because of the large aileron hinge moments and the excessive stretch of the control cable. These characteristics prevented the pilot from using what would normally be full aileron and in one instance imposed a severe limit on the aileron control at high speeds. The need for improvement in design to permit full deflection of the ailerons was indicated.

Many of the airplanes investigated displayed strong tendencies to turn in the direction of a low wing following a disturbance from laterally level flight, with resulting difficulty in maintaining a straight course in rough air. In certain instances yawing occurred against full rudder with the wing down less than 5°. As a result of this characteristic, increased demands were made on the ailerons to maintain the wings level.

The effectiveness of the elevator and the rudder controls was adequate in all the machines tested.

Lateral controls for use with full-span flaps.—Because of the inadequency of partial-span flaps on airplanes with the high wing loadings now contemplated, the development of an acceptable lateral-control device for use on wings employing high-lift devices over the entire span will be necessary.

An investigation has been made in flight (Technical Note No. 714) of retractable ailerons on a wing of 5:1 taper equipped with full-span plain flaps. Although the lateral control obtained with this particular installation was considered inadequate, the deficiency can apparently be ascribed to the fact that the aileron span amounted to only 33 percent of the wing span. With conventional ailerons of approximately the same span, mounted on the same wing, the airplane was equally deficient in lateral control. The lack of an appreciable stick force required to operate the retractable ailerons was considered too small to be desirable for a small airplane, although these ailerons appeared to be satisfactory in other respects.

The investigation in the 7- by 10-foot wind tunnel of lateral-control devices to be used in conjunction with full-span flaps has been continued. The equipment has been modified to make possible a more accurate determination of the time-response characteristics of the various devices than was heretofore possible. Comparative tests have been made on a large variety of devices on plain wings and on wings with full-span split and slotted flaps. The static rolling and yawing moments were determined for all the devices, and the time-response and the hinge moments were determined for most of the devices.

In recent investigations two lateral control systems have been developed for use with full-span flaps, both of which appear to offer promise for successful application.

STABILITY

The investigation of flying qualities has contributed much information on the stability of existing airplanes. Several points of general weakness have been noted and are being carefully studied. All the airplanes tested have displayed a tendency to spiral with the controls free. The situation is not considered serious, but complete stability is believed to be a desirable if not an essential characteristic when the requirements do not conflict with those of other essentials. In this connection, it has been noted that irreversible controls or a great amount of control friction are not remedies. When such measures were used, the lack of self-centering action of the controls masked the inherent

stability characteristics of the airplane and always produced a condition of apparent instability.

Many of the airplanes would be improved by increased directional stability. In one case a large diving moment was found to occur when the airplane was yawed. This characteristic, together with nearly neutral directional stability, resulted in frequent changes in longitudinal trim and a general feeling of uncertainty on the part of the pilot. Increased vertical fin area increased the steadiness of this airplane.

Observations of the angles of bank and the accompanying angles of yaw during steady sideslips have indicated a general inability of modern airplanes to develop cross-wind force. As a result of this characteristic, the pilot can judge the severity of a sideslip only by the rudder force and, where the directional stability of the airplane is small, large angles of yaw may be unknowingly attained. In some cases it was found relatively easy to obtain such large angles of yaw that the vertical tail stalled and directional instability was produced. This condition is to be avoided, particularly in large airplanes, in view of the large rudder forces required to regain control.

As a class, the low-wing monoplanes tested have been undesirably weak in longitudinal stability. The midwing and the high-wing monoplanes have exhibited somewhat more satisfactory characteristics, particularly at low speeds, where an increasing degree of stability is desired as a stall warning. None of the airplanes, however, has been completely satisfactory in this respect.

Several studies dealing with the stability of the complete airplane are still in progress. An analysis of the relationship between the longitudinal-control characteristics and the elevator-control effectiveness is practically complete, and a report on the subject will be shortly prepaid. The analysis indicates that although the elevator force required for steady flight varied directly with the degree of stability, the force required to produce speed changes decreased only 50 percent when the center of gravity was moved rearward 15 percent of the wing chord to the position that gave zero stability. The investigation of lateral stability with the automatic pilot is also nearing completion. Charts have been drawn to show the correlation of rudder and aileron mechanisms for stability. These data are being prepared for publication.

The function of the rudder and the manner in which this control is influenced by the degree of lateral stability are being investigated. Several tentative criteria have been formulated that when completed may be used directly in design.

A model has been built and tests have started with the gust-tunnel apparatus to determine the effect of longitudinal stability on the structural loads due to gusts.

Research has been continued on the influence of the design variables on the stability derivatives. The effect of yaw on the lateral-stability characteristics of four N. A. C. A. 23012 wings tested in the 7- by 10-foot wind tunnel is described in Technical Note No. 703. The wing variables investigated were taper, sweep, dihedral, and flap deflection. Technical Note No. 730 describes the effect on the stability characteristics of the position of a rectangular N. A. C. A. 23012 wing when combined with a circular fuselage. The wing was tested in three positions—high, mid, and low. The difference between the high and the low positions was approximately equivalent to 5° dihedral.

Tests have also been made in the 7- by 10-foot wind tunnel to obtain an indication of the difference between single and twin vertical tail surfaces as regards their contribution to the static directional and control forces.

In order to aid in the design of horizontal tail planes for longitudinal stability, a large number of stream-angle and dynamic-pressure surveys have been made in the wake of airfoils and wings of airplane models and airplanes. These data have been correlated with theory. The downwash angles computed from the theoretical span-load distribution were found to be in satisfactory agreement with the experimental results. It was also found that by theoretical treatment the wake characteristics can be predicted in terms of distance behind the trailing edge of the wing and the profile-drag coefficient of the wing. The results of this work are presented in Technical Report No. 651.

Technical Report No. 648 presents graphs from which the airplane designer may readily determine the downwash angle in the tail-plane region for elliptical and tapered wings within a practicable range of aspect ratios and with various flap arrangements. Charts and formulas are also included for evaluating the wake width and the velocity distribution in the wake.

The designer has been provided with information on the aerodynamic characteristics of tail planes by an extensive series of tests made on an isolated tail plane in the full-scale tunnel. The effects of various types of elevator nose shape, amount of elevator balance, and gap between the elevator and the stabilizer were investigated. In addition to the usual force-test results, determinations were made of the elevator hinge moment for all conditions, including the use of various sizes of tab. Technical Report No. 675 presents these data.

Further information on the aerodynamic characteristics of the tail surfaces is being furnished by the measurement of section characteristics in the 4- by 6-foot wind tunnel. The test program calls for the systematic variation of elevator or rudder chord and a detailed study of different means of balancing the hinge mo-

ments. The first phase of the work, consisting of pressure distribution tests of an N. A. C. A. 0009 airfoil with three sizes of unbalanced movable surfaces each with three sizes of tabs, is well advanced. One paper on the subject has been prepared for publication.

During the past year, the laboratory facilities for the study of stability have been augmented by the completion of a new 12-foot free-flight wind tunnel. The construction of this tunnel completes the development of the free-flight type of tunnel that has been in progress for several years. In this type of wind tunnel, a model is flown by remote control free from any restraint. Continuous observations may be made by a stationary observer of the inherent and the controlled stability, the motion in gusty air, the stalling characteristics, and many other factors directly related to the free-flight behavior of the airplane. Preliminary investigations on the stability of two service airplanes conducted in the model of the tunnel used for development work have indicated that the 12-foot free-flight tunnel offers a useful, rapid, and relatively inexpensive means for the study and the correction of the stability and the handling characteristics of new airplane designs. The 12-foot tunnel is being calibrated, and testing will shortly be started.

SPINNING

The determination, and improvement where needed, of the spinning characteristics of new service airplane designs in the 15-foot free-spinning wind tunnel have been continued. During the past year the characteristics of five specific designs were inspected. As usual, the findings in these investigations were immediately transmitted to the service organizations concerned. The Committee, however, has also compiled and analyzed all such data in the files. As a result of this analysis, an empirical spin criterion has been formulated that can be used in design by laying out the tail surfaces for the most favorable spin-recovery characteristics. The criterion has been presented in Technical Note No. 711.

A further analysis of the data from routine tests has been made in an attempt to obtain a more complete understanding of the action of the ailerons in a spin and during the recovery. The effect of the ailerons was found to be intimately related to the mass distribution of the airplane. With a knowledge of the mass distribution, it is now possible to predict whether the ailerons should be set for or against the spin for most rapid recovery. The possibility of using the ailerons with an abnormal displacement as an antispin device has also been investigated. A paper on the subject is now in preparation.

The reliability of the information on spinning characteristics obtained from the free-spinning tunnel is a matter of some concern. The Committee, with the cooperation of the services, now receives information on the spinning characteristics of full-scale airplanes the models of which have been previously tested in the tunnel. A comparison of considerable full-scale data with the model data indicated that the wind-tunnel data correctly predicted the full-scale spinning characteristics in 80 percent of the cases. In 10 percent of the cases, the tunnel results were conservative. In only 10 percent of the cases did the model results give an optimistic prediction of the recovery of the corresponding airplanes. Ways of improving the reliability of the tunnel are being considered.

One evident contributing factor to the difference between the model and airplane characteristics is the low scale of the model tests. The influence of scale is being studied in a limited range by comparison of two different-size models of the same airplanes.

The investigation of the relative importance of wing arrangement, tail arrangement, and mass distribution on the spinning characteristics of low-wing monoplanes, started 2 years ago, has been completed. Reports have been published dealing with the effect of changing the relative distribution of mass along the wings and the fuselage and of changing the fore-and-aft position of the center of gravity (Technical Report No. 672). A report dealing with the effect of relative density of the airplane, or its equivalent, the altitude of the spin, is in preparation. Data on the final phase of the work, the effect of a percentage change in the radii of gyration about all three axes, are now being analyzed.

STALLING

The investigation of the stall of an airplane and of the means of improving it has been continued. In conjunction with the investigation of flying qualities, inspection is being made of the stalling characteristics of existing airplanes. It has been found that tip stalling is not always entirely responsible for undesirable characteristics. One airplane, for example, that rolled violently when stalled with flaps up was observed to settle with some degree of lateral control when the flaps were extended, even though tuft observation showed that tip stalling was accentuated with the flaps extended. The development of the stall with the flaps extended was sufficiently symmetrical so that no large lateral disturbances occurred.

Of the airplanes tested, those that possessed strong longitudinal stability were rated by the Committee's pilots as having the best stalling characteristics. In these airplanes, where the stall was produced only as a result of a definite forceful use of the elevator control, the stall was robbed of the element of surprise. Under these conditions, the undesirable character of the stall appeared much relieved.

Despite the contributing effects of other factors as shown by the flight tests, the wing characteristics con-

tinue to remain the chief factor in the stalling problem. Several projects are in progress dealing with this phase of the problem. The investigation in the variable-density wind tunnel mentioned in last year's report to determine the relative efficiency of various methods, such as twist, change of section, and change of camber, for the prevention of tip stall is well advanced. Technical Note No. 713 has been published presenting a comparison of several tapered wings in the design of which these methods are employed to avoid tip stalling. It is concluded that for aerodynamic equality and no tip stall, ratios of tip chord to root chord of between one-third and one-half will give the lightest wings. The analysis on which the paper is based is now being extended to obtain general design charts dealing with the stalling of tapered wings. The tests to determine the spanwise progress of the stall of several representative wings with different amounts of taper and sweep have been completed, and the analysis of the results has been started.

If the stalling of the wing tip of a highly tapered wing can be delayed to a higher angle of attack than that of the center section, the lateral stability and the useful maximum lift coefficient of the wing will be greatly improved. One effective method of accomplishing this end is the incorporation of slots in the tip portion of the wing. Tests have been made in the 7- by 10-foot wind tunnel of an N. A. C. A. 23012 airfoil with and without a slotted flap to develop fixed slots that can be employed to increase the useful range of angles of attack. The results of these tests (Technical Note No. 702) show the best position of the slot to be near the leading edge of the airfoil. One arrangement of the fixed slot increased the angle of attack for maximum lift 11° for the plain wing and 10° for the wing with the slotted flap. The chief disadvantage of the fixed slot was the increase in drag at low lift coefficient.

Technical Note No. 670 has been published describing the mechanical stall-warning device discussed in the last annual report.

MANEUVERABILITY

The investigation of the maneuverability of Navy airplanes has been continued, and tests on the third and the fourth airplanes of the series have been completed. Originally undertaken to determine the maximum angular accelerations to which an airplane might be subjected, the investigation has now been extended to include studies of the effect of unorthodox manipulation of control stick and tabs.

Flight investigations of the maneuverability of several Army pursuit airplanes have also been completed during the past year. The results have shown that from the pilot's viewpoint maneuverability is greatly affected by the characteristics of the longitudinal control. Airplanes possessing neutral or slight longitudinal stability, and consequently very little control movement to offset large changes of angle of attack, were found to be subject to inadvertent stalling in accelerated maneuvers.

TAKE-OFF

The important factors influencing the take-off performance of an airplane are wing loading and power loading. These factors are ordinarily prescribed by the high-speed flight condition and cannot be modified to decrease the take-off run. Consequently, the most practical solution to the problem of improving take-off performance appears to lie either in the development of better high-lift devices for use during take-off or in the improvement of the characteristics of propellers operating under take-off conditions.

During the past year the Committee has conducted two propeller investigations that provide data having a direct bearing on the take-off problem. The results of the first of these investigations, published in Technical Report No. 650, include data from tests of full-scale propellers in the propeller-research tunnel indicating the effect of airfoil section on take-off efficiency. The second investigation, which was made on the special static-thrust apparatus mentioned last year, supplied data on the static thrust of full-scale propellers. These data should prove useful in estimating the distance required for take-off.

LANDING

The investigation of the landing characteristics of airplanes to obtain statistical information on the vertical velocities and accelerations in landings has been continued. The evaluation of the data obtained in the tests mentioned in the last annual report has been completed, and the results have been reported to the Army Air Corps and to the Bureau of Aeronautics, Navy Department. Tests of four additional airplanes, including one equipped with a tricycle landing gear, have been made. The results for three of these airplanes have already been reported to the Civil Aeronautics Authority, the Army Air Corps, and the Bureau of Aeronautics, Navy Department. A number of one-wheel landings were included in the tests of one airplane to obtain information concerning the effect of the lateral landing attitude of the airplane with respect to the landing surface upon the maximum loads sustained by the landing gear.

In addition to landing tests involving conventional landings, an investigation has been made of vertical velocities and attitudes and of the resulting landing-gear loads encountered in blind or instrument landings of Army bombers of two different types. The results obtained with one type of bomber have been reported to the Army Air Corps and a report on the results for the other type has been prepared. The maximum vertical velocities in such landings were found to be twice as great as the maximum values for normal landings.

The results of the landing tests made thus far with airplanes equipped with tricycle landing gears have indicated that the maximum nose-wheel loads are likely to be encountered in approximately three-point landings. Nose-wheel loads encountered in two-point landings, wherein the airplane pitches forward after impact on the main wheels, are not likely to be critical.

By use of the apparatus mentioned in the last annual report, tests have been conducted for the purpose of determining the friction required to prevent the shimmy of a castering wheel. Various wheels and tires were tested under varying loads and with varying caster lengths and spindle angles. One interesting feature of the results was that they indicated the desirability of making the inclination of the spindle small. A report presenting the results of these tests is being prepared for publication.

The investigation of ground effect by means of a glider towed by an automobile, which was mentioned in the last annual report, has been completed and the results are being prepared for publication. For most of the conditions tested, which included full-span flaps, the agreement between the experimental results and the ground-effect theory, as regards effects on angle of attack and drag, was reasonably good.

Tests to determine the ground effect on the aerodynamic characteristics of rectangular and tapered wings, both with and without split and slotted flaps, have also been made in the 7- by 10-foot wind tunnel. In these tests the ground was simulated by the use of a plane located various distances from the model. It was found (Technical Note No. 705) that the ground effect on wings with flaps is a marked decrease in drag, a decrease in diving moment, and a substantial reduction in maximum lift.

AIRFOILS

Section characteristics.—In the last annual report there was considerable discussion of attempts to correlate and reconcile the airfoil data obtained from various sources. Methods of correcting the standard characteristics of airfoil sections determined from tests in the variable-density wind tunnel to allow for turbulence, strut interference, and other features had been evaluated, and the results were published in Technical Report No. 669. In spite of these efforts, however, the situation was unsatisfactory and new methods of making airfoil studies seemed necessary. The presence of turbulence in wind-tunnel air streams had long been a source of trouble and uncertainty and the transition from laminar to turbulent flow was known to be affected by this turbulence in the stream.

At the same time, increasing knowledge of boundary-layer phenomena had given strong indications of the possibility of more extensive laminar boundary layers and consequent lower drags than have been available with conventional airfoil sections. At least two facts were outstanding: First, airfoils should be designed to take advantage of true low-drag laminar boundary layers over a greater portion of the airfoil; and, second, a nonturbulent air stream as nearly comparable as possible with free-air conditions should be provided to test the new airfoil shapes.

The procurement of such equipment was begun some time ago by the Committee and about a year ago a low-turbulence wind tunnel became available. This tunnel, which is somewhat unusual in design, has a test section 3 by 7½ feet, and is arranged for the testing of large models having chords of several feet and only 3-foot span in essentially two-dimensional flow. The usual methods of measuring the stream turbulence were not considered sufficiently sensitive; direct comparisons of transition on airfoils from measurements in flight, in the new wind tunnel, and in other tunnels, were therefore made. The turbulence level of the new tunnel was found to be well below the level of other wind tunnels of the Committee; nevertheless, it seemed improbable that the desired effective zero turbulence had been attained. It was considered sufficiently low, however, pending more reliable comparisons with flight, to justify some preliminary investigations.

These preliminary investigations were started by the development of new airfoil forms that, when tested in the new equipment, immediately gave drag coefficients of one-third to one-half the values obtained for conventional sections. These studies have been extended to the 8-foot high-speed tunnel and to flight with substantial agreement as to the possibilities of the new airfoils. This work is being continued both in flight and in the low-turbulence tunnel. Extension of this work into the field of compressible flow is being carried on in the 24-inch and 8-foot high-speed wind tunnels.

Wing characteristics.—The calculation of wing characteristics has been continued, and the methods and results of comparisons with tests which included wings with partial-span flaps have been presented in Technical Report No. 665. It now seems that the knowledge of the section characteristics is sufficient to make possible the determination, with an accuracy sufficient for many practical purposes, of the important wing characteristics for any particular wing design. Efforts in airfoil work may now be concentrated on the determination of accurate section characteristics.

Surface roughness.—The results of tests mentioned in the 1937 annual report showing the effects on wing drag of countersunk and protruding rivet heads, of spot welds, of several types of lapped joints, of surface roughness, and of manufacturing irregularities have been supplemented by data from additional tests and

published in Technical Note No. 695. This note suggests a method of estimating the effects of rivet heads and lapped joints for conditions outside the range of the tests with respect to Reynolds Number or rivet and lap size and arrangement. The method depends on estimating separately the drag increments due to premature transition and to the direct drag of the irregularities. As an example, it is shown that a typical arrangement of rivets and lapped joints on the rear 75 percent of the wing of a large airplane which has a total wing area of 3,600 square feet flying at 250 miles per hour will increase the drag sufficiently to require 180 horsepower more than would be necessary if the wing were smooth.

Additional irregularities investigated have included surface waviness and rib stitching. (See Technical Note No. 724.) The results of the tests of waviness may be simply summarized. Small waves such as occur on wings made according to present standards of workmanship will not seriously increase the drag unless they precipitate premature transition or premature compressibility effects; that is, unless they occur on the forward part of the wing. A single wave only 0.020 inch high and 3 inches wide located 10.5 percent of the chord from the leading edge of an N. A. C. A. 23012 airfoil was sufficient to cause transition to occur at the wave with a consequent drag increase. Rib stitching corresponding to a rib spacing of 6 inches increased the drag 7 percent; the drag increment was proportional to the number of ribs for larger rib spacings. About one-third of the drag increase was due to the premature occurrence of transition at the forward ends of the stitching.

AERODYNAMIC INTERFERENCE

For several years the Committee has been conducting in the variable-density wind tunnel a general investigation of fundamental character into the aerodynamic interference between the component parts of airplanes. The initial part of the investigation, described in Technical Report No. 540, comprised tests of 209 combinations of wing and fuselage, in which the variables studied included form of wing, shape of fuselage, position of wing relative to fuselage, and form of wing-fuselage juncture. Subsequent reports dealt with more complete investigations of the same variables and with an extension of the program to study the interference associated with tail surfaces added to wing-fuselage combinations (Technical Report No. 678). The general investigation is now nearing completion with a program of tests of nacelles in combination with a round fuselage, a tapered wing, and conventional arrangement of semielliptical tail surfaces. Two sizes of streamline nacelles and one of conventionally cowled nacelles are being investigated. Although the program is not yet completed, the results thus far indicate that the adverse interference of streamline nacelles of moderate size on the maximum lift is difficult to control. Further, the drag increase is appreciable and strengthens the conclusion that high-performance airplanes should comprise the minimum number of efficient component parts, efficiently combined. It is therefore desirable that nacelles be eliminated in airplane design.

An extensive investigation of a similar nature but including also the effects of propellers is in progress in the full-scale wind tunnel. An investigation is now under way on a complete airplane model for the purpose of evaluating the effects of air-cooled engine nacelles of the conventional type with N. A. C. A. cowlings over a large range of design conditions. The sizes and numbers of nacelles correspond to arrangements on large four-engine and small high-powered two-engine airplanes. The ratio of nacelle diameter to wing thickness is varied from 0.5 to nearly 4.0 and the position of the nacelles is varied relative to the wing chord line and the leading edge. A study is being made of the nacelle drag, the propulsive efficiency, and the effects of the nacelles on the pitching moment and the maximum lift coefficients of the model.

In the 20-foot wind tunnel, further tests have been made of wing-nacelle-propeller combinations. The first series of tests dealt with the effect of nacelle-propeller diameter ratio on body interference (Technical Report No. 680). This investigation was followed by tests of several model nacelle-propeller arrangements in front of an N. A. C. A. 23018 wing. Data were obtained on the internal air flow, the drag, the interference drag, and the propulsive efficiency. The results, which will be published soon, are in accord with those of earlier investigations.

Supplementing tests of a few years ago, in which the drag of normal landing gears was determined, an investigation has been made in the 20-foot tunnel to determine the drag of the nose-wheel component of tricycle landing gears. The variables studied included size of wheel, form of supporting struts, form of fairing, position of nose wheel with respect to the fuselage, and degree of wheel retraction within the fuselage. For the partly retracted condition, no material reduction in drag below that of the completely exposed gear was noted except when the nose wheel was halfway retracted into the very nose of the fuselage. In this condition the gear drag was negligible.

Another extension of the interference research dealing with the effects of compressibility is considered under the subject of compressibility effects.

COMPRESSIBILITY EFFECTS

Technical Report No. 646 has made available a large amount of information on the nature of compressible-flow phenomena. As a result of this fundamental work, conducted in the 24-inch high-speed wind tunnel, and a study of the information gained as it may affect actual designs of high-speed airplanes, it appears that the propeller will offer the most serious problems. Other parts of the airplanes may be so designed as to avoid serious compressibility losses. The propeller problem is the most serious because the propeller operates at higher relative air speeds than the other parts of the airplane and because its efficiency is decreased by the relatively large section thicknesses commonly used near the blade roots.

At present, therefore, the greatest emphasis is being placed on the development of suitable blade sections for high-speed propellers. Based largely on the data presented in Technical Report No. 646, new sections have been designed and experiments are being conducted in the 24-inch high-speed wind tunnel. Tests already made show that considerable improvement may be obtained. Meanwhile, further fundamental investigations to study the nature of compressible-flow phenomena, particularly at and near the critical speed, are being conducted in the 11-inch high-speed wind tunnel.

It is important to understand, however, that considerable care must be exercised in the design of other components of the high-speed airplane. An investigation in the 8-foot high-speed wind tunnel of a model of a typical transport airplane illustrates two important sources of difficulty: First, misalinement of nacelles having N. A. C. A. radial-engine cowlings with the air flow may result in important decreases of the nacelle critical speed; second, mutual interference between the parts of an airplane may reduce its critical speed below that of any of the individual parts when tested separately. In the case of the transport model investigated, the critical speed of the nacelles was 30 miles per hour lower than the critical speed of the same nacelles isolated from all the other parts of the airplane except the wing. Similar effects must be considered when any two or more basic shapes are combined.

PROPELLERS AND PROPELLER-BLADE SECTIONS

An extensive program of propeller research conducted in the propeller-research tunnel has been concluded. A large portion of this work has been described in previous reports. Technical Report No. 650, dealing with tests of propellers having different blade sections, and Technical Report No. 658, dealing with tests of propellers having different pitch distribution, have been published during the year. Differences of 3 percent in maximum efficiency were found for the propellers having different blade sections. Differences in take-off efficiency were much larger. The effects of changes in pitch distribution appeared to be small. It is important to note, however, that at very high blade angles the use of a spinner materially increased the maximum efficiency. The concluding report of this series, yet to be published, deals with an investigation of static thrust conducted on a special outdoor test rig.

Force tests were conducted on three full-scale propellers in conjunction with the more streamlined afterbody mentioned in the discussion of cowling research. Comparisons were made with a streamline nose and an open-nose cowling in front of the better afterbody. The results of these tests are being analyzed on the basis of the preceding propeller data and a report is being prepared presenting this information.

Sufficient data are now available so that a fair approximation to the efficiency and power absorbed can be made in the usual cases. It has been noted, however, that peculiar disturbances occur with some cowling forms and it has been impossible to predict these in advance, so that anomalous efficiencies may be expected in some cases. The poor efficiencies often calculated from flight tests as compared with wind-tunnel results have now been quite conclusively proved to be really an effect of reduced horsepower output. The installation of dynamometers on engines in flight has settled this question and more extensive use of this apparatus may be expected.

The present knowledge of propeller art and the increasing speeds and power to be expected with aircraft likely to be developed in the near future indicate that serious propeller problems may be expected. The limitation in tip speed imposed by compressibility phenomena is of increasing importance because actual aircraft speeds will soon be nearly as great as present propeller critical tip speeds. Important design compromises may be necessary to avoid serious compressibility losses. Such compromises may lead to decreased efficiency unless extreme care is used in design. Solidity higher than any values heretofore used is indicated because of tip-speed limitation and increased engine power. Increasing speeds will lead to very high pitch settings so that rotation losses will become important. Considerable study has been given the problem and, as a result, a program of blade-section development is being conducted in the 24-inch high-speed wind tunnel to lead to the development of blade sections that will have higher critical speeds and decreased drag.

As the data become available, the results are being analyzed to study the application to the design of optimum propellers for high-speed aircraft. Work is

now proceeding on the design of a family of propellers having the best blade sections obtainable to reduce the blade drag and compressibility losses and having thrust distribution designed to attain minimum induced loss. The range of solidity has been increased to include the extreme values likely to be encountered. An investigation of counterrotating propellers conducted at Stanford University and financed by the Committee indicates important increases in efficiency likely at high pitch settings. Further study will be made so that good propeller efficiency may be maintained through the elimination of the large rotation loss that occurs at high pitch settings.

An analysis of the operation of the propeller by the use of the distribution of the thrust and torque along the blades combined with theoretical equations has been made. The data for the analysis were obtained in the N. A. C. A. 20-foot wind tunnel on a 2-blade propeller of 4-foot diameter operating in front of four body shapes ranging from a small shaft to support the propeller to a conventional N. A. C. A. cowling. A method of estimating the axial and rotational energy in the wake as a fractional part of the propeller power is given. The average angle of twist in the propeller slipstream is shown to be a function of the torque coefficient Q_c and charts are given to aid in estimating the angle. Counterrotating propellers are shown to be attractive from considerations of aerodynamic efficiency when the propellers are highly loaded. A report on this work is in the process of publication. Similar work was conducted on two full-scale propellers differing only in pitch distribution along the blades. A report is being prepared on this work.

COWLING AND COOLING

General conditions.—For several years it has become increasingly apparent that better solutions for the cowling and cooling problems are required to meet the demands of the military services for increased airplane performances. Work is still in progress dealing with the development and improvement of the N. A. C. A. cowling, but it now appears that marked advances are at hand through the application of fundamental aerodynamic principles to the problems of cooling.

The present approach to the subject considers the problem divided into two separate ones: The internal-cooling problem; and the residual problem having to do with the scoop, vent, duct, and external-flow conditions. The internal cooling is chiefly a problem of heat transfer from the cylinder or radiator. Considerable progress has been made toward the desired objective of this phase of the problem—to minimize the quantity of air required and to minimize the local internal work of cooling. This internal work, the product of the pressure drop across the cooling unit by the volume per second of air employed, is of fundamental importance because it represents a power-loss increment associated with the heat-transfer mechanism.

The external-flow phase of the problem is approached by considering this power-loss increment and air quantity as specified and then attempting to minimize the resulting power loss associated with the complete system. A certain power-recovery increment may fortunately be associated with the thermodynamic cycle of the cooling system (Meredith effect).

Energy from the propeller slipstream should be readily available. One of the most promising systems of this type, which has been under investigation in the propeller-research and the full-scale tunnels during the year, employs openings in the leading edge of the wing in the propeller slipstream. Other systems, however, may represent a close approach to the ideal, including the wing-duct systems investigated in the 7- by 10-foot tunnel and the full-scale tunnel and also certain applications of the N. A. C. A. cowling under investigation in the 8-foot high-speed tunnel. The results already obtained with several of these systems suggest that, with careful aerodynamic design of the inlet and outlet openings and the internal-duct systems, a close approach to the ideal performance of these units may be realized. It thus appears that practical systems are within reach for which the power recovery may exceed the power loss and that, for high-performance airplanes, the cooling system may become an asset rather than a liability.

It should be emphasized, however, that high-performance systems must be of fundamentally correct design. Many tests of modern pursuit-type airplanes in the full-scale tunnel have shown large drag losses associated with the cooling and scoop systems commonly employed. Moreover, the difficulties can seldom be adequately corrected because the original design did not include adequate provisions for a fundamentally correct cooling system.

Cowling research.—The study of the pressure available for ground cooling in front of the cowling of an air-cooled engine discussed in the last annual report is described in Technical Note No. 673. The design report on cowling for radial air-cooled engines is presented in Technical Report No. 662.

The results of flight tests of four designs of nose-slot cowlings with several variations in each design are presented in Technical Note No. 720. The results describe the development of the nose-slot cowling from flight data. A sample design calculation involving the use of results from flight, wind tunnel, and ground tests is given in an appendix to illustrate the design procedure.

An investigation of full-scale nose-slot cowlings has been conducted in the 20-foot wind tunnel. Engine conductivities from 0 to 0.30 were investigated. Two basic nose shapes were tested to determine the effect of radius of curvature of the nose contour; with the nose shape with the smaller radius of curvature the higher pressure drop across the engine was obtained. The best axial location of the slot for low-speed operation was found to be in the region of maximum negative pressure for the basic shape for the particular operating condition. The effect of the propeller operating condition on the available cooling pressure was determined. The maximum nondimensional pressure drop obtained for the high-speed condition with an engine conductivity equivalent to that of a modern double-row radial engine and a propeller with good blade sections near the hub was 1.45, and for the take-off condition, 3.75. For the propeller with a round blade shank, the values were 1.23 and 1.65, respectively. A report on this work is in the process of publication.

The drag and the power cost associated with the changing of the nose of a nacelle from a streamline shape to a conventional N. A. C. A. cowling shape was investigated in the 20-foot wind tunnel. Full-scale propellers and nacelles were used. The increment of drag associated with the change of nose shape was found to be critically dependent on the afterbody of the nacelle. Two streamline afterbodies were tested. The results of the tests with the more streamlined afterbody showed that the drag approached that of an airship form and that the added drag due to the open-nose cowling was only one-fourth of the drag increase obtained with the other afterbody.

From the experience gained in the investigation of the nose-slot cowling, it was found that the cowling exit would work efficiently if the after part of the body allowed the air to flow smoothly without breakdown of flow in that region. If the shape of the exit allowed breakdown of flow to occur, the slot created high drag and very low available pressure drop across the baffles. From a consideration of the available pressure behind the propeller, it was believed that, if a good exit slot design were used, much higher available pressure drops could be obtained by the use of cowling flaps than is usually supposed. Tests were therefore made to determine the available pressure drop for cowling flaps, care being taken to provide good flow conditions at the exit slot. The pressure drop available for cooling with a conductivity equivalent to that of a double-row radial engine was found to be 4.85 for the take-off condition for a propeller of good blade section and to be 3.17 for the propeller with round blade shank. A report on this work is being prepared.

An investigation in which blowers of various forms were used, in particular in the inlet passage of a modified N. A. C. A. cowling, has been made both on models in the propeller-research tunnel and in flight. Although the blower absorbs some power, it is evident that there is a definite advantage in reduced drag, in higher propeller efficiency because of the covering of the hub, and in greatly improved cooling. In one case it has been possible to run the engine continuously on the ground with much lower (85° to 100° F.) temperatures than were obtained in flight with a normal cowling. Ground cooling is of importance in some types of aircraft and better cooling at higher speeds with large engines is necessary. Several reports have been prepared discussing various phases of the problem, and the investigation is being continued.

Wing-duct radiators.—As an extension of the investigation conducted in the 7- by 10-foot wind tunnel on full-span cooling ducts, tests have been made in the full-scale wind tunnel of similar ducts of finite span in a large wing for the purpose of evaluating end effects and investigating the scale effect on the characteristics of the ducts. In the investigation in the full-scale wind tunnel, a special study was made of means for regulating the quantity of air flow for the various flight conditions, particularly in regard to obtaining sufficient cooling air for the climb condition without an excessive amount for the high-speed condition, which would result in a serious penalty in drag.

The ducts of the more efficient types were found to affect inappreciably the maximum lift coefficient of the wing. Tests with operating propellers in front of the ducts indicated that ground cooling would be satisfactory and that in the climb, if the radiator inlet was placed behind the upgoing propeller blades, the cooling-air quantity would be increased about 10 percent. Tests conducted with heat applied to the radiator element indicated that some recovery of the energy lost in cooling is possible.

WINDSHIELDS

A systematic series of windshields, of both the transport and the closed-cockpit types, was tested in the 8-foot high-speed wind tunnel to indicate the drag of conventional types and to determine how these conventional types can be improved. It appeared that a typical transport-type windshield might account for about 21 percent of the fuselage drag but that it should be practicable to construct a windshield, with either single-curved or double-curved glass, that would account for only about 2 percent of the fuselage drag. It also appeared that recessed windows should be avoided.

Typical closed-cockpit windshield (including canopy), such as are used on small fighting airplanes, in some cases appeared to account for 15 percent of the drag of the entire airplane, but by improved design the windshield drag should be almost eliminated.

THEORETICAL AERODYNAMICS

Normal-force and pressure distribution over airfoils.—A relatively exact and simple method for the prediction of the chordwise normal-force distribution over an airfoil was developed by the Committee in 1938. As mentioned in the last annual report, this method is applicable to ordinary airfoils and to airfoils equipped with plain, split, or serially hinged trailing-edge flaps. The pressures acting on the upper and the lower surfaces of the airfoils, however, are not separately determined by this method. A method of determining these individual pressures has been described in a report recently published (Technical Note No. 708). This method permits the determination of the pressure distribution over an airfoil section when the normal-force distribution (from Technical Reports Nos. 631 and 634) and the pressure-coefficient distribution over the "base profile" (that is, the profile of the same airfoil if the camber line were straight and the resulting airfoil at zero angle of attack) are known. Distributions of the base-profile pressure coefficients for the usual N. A. C. A. family of airfoils, which are also suitable for several other commonly employed airfoils, are included in Technical Note No. 708.

Compressibility effects.—Theoretical investigations of the effect of compressibility on the flow past obstacles have been continued. In particular, the effect of compressibility on the moment of an arbitrary shape has been obtained and the general formulas have been applied both to elliptic cylinders and to symmetrical Joukowsky profiles. The results of this investigation have been presented in Technical Report No. 671.

Span load distribution on wings.—A simple method of successive approximation for determining the span load distribution on wings has recently been developed by the Committee and the results published in Technical Note No. 732. A straightforward arithmetical procedure is described in which component loads are added to form the distribution sought. The proportions, the magnitudes, and the relative spanwise positions of these component loads are determined from equations derived from the differences between the given chord distribution and the chord distributions associated with the components themselves. The method is comparatively rapid and should prove useful in problems for which the span load distributions cannot otherwise be readily determined.

WIND-TUNNEL CORRECTIONS

Profile-drag measurements by momentum method in full-scale wind tunnel and in flight.—The accurate measurement of the profile drag of a wing by means of surveys of dynamic and static pressure in its wake is of importance because it makes possible the evaluation of the drag of various types of protuberance on the wing and, by comparison with known characteristics of aerodynamically smooth wings of the same dimensions, the evaluation of the drag caused by surface roughness and manufacturing irregularities. In order to investigate the accuracy of this method and the reduction of the test data by the Jones and the Betz equations, wake surveys and force tests were made in the full-scale wind tunnel on three symmetrical airfoils of different thicknesses. An analysis of the results as presented in Technical Report No. 660 shows that, for zero-lift condition, the profile-drag coefficients reduced by either the Jones or Betz equations agree with the force-test results within 2 percent. For the lifting airfoil, the error resulting from the induced field did not exceed 2.5 percent up to a lift coefficient of 1.0 and outward to a spanwise position of about 0.8 of the semispan.

The effects of turbulence present in the jet of the full-scale wind tunnel were determined by comparative velocity surveys in the boundary layer and wake momentum measurements of a polished section of a wing on an airplane in flight and in the tunnel. The results of the boundary-layer velocity measurements (presented in Technical Note No. 693) show that the end of the transition from laminar to turbulent flow occurs at approximately the same position in flight and in the tunnel but that the transition region as measured in the tunnel is somewhat broader than for flight. This difference in the boundary layer, however, accounts for an increase of only 0.0001 in the profile-drag coefficient as determined by the momentum method over the values obtained in flight.

The 8-foot high-speed wind tunnel.—An investigation of N. A. C. A. 0012 airfoil of 5-foot chord has been made in the 8-foot high-speed wind tunnel, which has a circular jet and a closed throat, to establish the spanwise variation of constriction caused by the presence of the airfoil. The results of this investigation will be used to determine the magnitude of the corrections to be applied to the results of later airfoil investigations.

EFFECTS OF ICE FORMATION AND ITS PREVENTION

Adhesion of ice to surfaces.—In the development of methods of preventing ice formation on aircraft parts, it is important to know the force with which ice adheres to various materials. From the magnitude of this force, recommendations can be made as to lines of development that should be followed to perfect a satisfactory de-icing mechanism. An investigation was made on the adhesion of ice to various materials and the results have been published in Technical Note No. 723. The procedure consisted in freezing water onto a block of the material to be tested and then determining the force required to remove the ice. Brass, copper, duralumin, stainless steel, glass, and micarta were tested. With the exception of micarta, the adhesion

force holding the ice to the block was greater than the cohesive force within the ice itself. In each case, the ice failed at a tension of about 140 pounds per square inch leaving ice adhered to the surface. With the micarta the ice failed irregularly at a loading of 53 pounds but remained adhered to the micarta block in sections of the surface.

The tests indicated that ice will adhere to any solid surface with a force so great as to eliminate the possibility of removing the ice by mechanical means suitable for aircraft. When rubber or a thin sheet of duralumin was used, the ice could be removed with a much lower force because of the "peeling" action that took place.

The tests showed that if a liquid interface were maintained between the ice and the solid surface the ice was easily removed. In this case the force to be overcome was chiefly that exerted by atmospheric pressure. With greases, the force was somewhat greater. The tests indicated that the commercial de-icing pastes essentially consisted of a freezing-point depressor combined with a substance to form a paste.

Adhesion of ice to aircraft parts.—In the ice-research program announced in the last annual report, chemical, heat, and mechanical means of ice prevention have been investigated. Attention has been given to the prevention and removal of ice from the airplane wing, the struts, the propeller, and the windshield. Under the existing program, attempts will be made to determine means for the protection of other parts of the airplane.

Flight tests in simulated icing conditions made with the inflatable-type wing de-icer indicated that only partial ice removal is possible by this method with present equipment. Residual ice accretions were observed on the leading-edge and the cap-strip regions of the de-icer. Tests to determine profile drag and maximum lift in flight have also been made on a wing equipped with a de-icer. Coefficients of profile drag and maximum lift were determined for the plain wing without the de-icer, with the de-icer free from ice accretions, and with several other drag conditions produced by attaching simulated ice formations to the regions of the wing leading edge and the de-icer cap strip. Formations on the de-icer cap strips were shown to have a very undesirable effect on the profile drag and the maximum lift.

An analysis of the results of the preliminary investigations conducted in the ice tunnel on the use of exhaust-gas heat for the prevention of ice on the airplane wings (Technical Note No. 712) indicated that a reasonably small percentage of the exhaust thermal energy will prevent the formation of ice on the wings. This work is being continued in analytical investigations and model tests both in flight and in the ice tunnel. The investigation of the use of steam heat in flight gave results similar to those from tests made with direct exhaust heat in the ice tunnel and indicated that the quantity of heat required for ice protection was not excessive. Investigations on the use of steam have been temporarily discontinued and emphasis is being placed on tests of direct exhaust heat, which seems to require less mechanical equipment than does steam.

The investigations of chemicals applied prior to flight for the prevention of ice on the airplane wing have been continued, although no satisfactory substance has been found when tested under simulated icing conditions. Alcohols and mixtures of alcohol and glycerin were discharged through perforations along the leading-edge region of a wing. In these tests the perforated surface and the distribution tube were attached to the surface of an inflatable de-icer. Tests conducted with and without the de-icer in operation failed to prevent or remove ice from the wing. A similar investigation with ethylene glycol and a mixture of ethylene glycol and isopropyl alcohol was made on a small strut such as might be used for an antenna mast. The discharged fluid prevented the formation of ice although the quantity required seemed to be excessive.

The distribution pattern of ice-inhibiting fluids over the blades of a propeller of large diameter has been studied in flight. The results indicate (Technical Note No. 727) that ducts or channels along the leading edge of the propeller blade will be required to distribute properly ice-inhibiting fluid on propellers of large diameter. Further studies are planned on the problem of preventing ice formation on the airplane propeller.

An investigation has been made of several methods of preventing ice on the airplane windshield. Models equipped for the application of electric heat and of heated air, and a rotating wiper blade that dispenses alcohol from its center have been tested. Ice was prevented on each of the model test panels when subjected to simulated icing conditions in flight. Air heated by the exhaust to a temperature of about 170° F. and passed through a $\frac{3}{16}$-inch gap between two panes of glass with a velocity of 50 feet per second prevented the formation of ice during very severe simulated icing conditions. This method seems to offer the simplest solution to the problem of windshield icing since it prevents ice on both sides of the glass, requires no moving parts, and utilizes what is otherwise waste energy.

ROTATING-WING AIRCRAFT

The possibility of improving the lift-drag ratio of rotors of rotating-wing aircraft in forward flight by retarding or preventing the stalling of the inboard elements of the retreating blades is being investigated. A preliminary step in this investigation was to supplement theoretical calculations of the operating condi-

tions of blade elements in various parts of the disk with photographic observations of the behavior of silk tufts mounted on the blades of a VG–1B autogiro. The tuft observations indicated that the portion of the rotor disk in which the elements are stalled is somewhat larger than would be expected from theoretical considerations. A technical note presenting the results of the initial observations is being prepared and additional observations on blades of various airfoil section and plan form are in progress.

An attempt is being made to isolate the factors in the design of rotor hubs and blades that are responsible for the severe vibration present in the control systems of present-day direct-control autogiros. To this end, the varying loads in the control system of a VG–1B autogiro have been recorded in flight at various air speeds. Analysis of the records indicates that mass unbalance or improper matching of the blades is not responsible for the control vibration in this machine and that some modification of hub and blades may be desirable. Similar tests on the same machine equipped with blades of improved design are now in progress.

Data on the blade motion and the control characteristics of nonarticulated feathering rotors have been obtained from flight tests of the Wilford XOZ–1 sea gyroplane and are being evaluated.

DETERMINATION OF MOMENTS OF INERTIA

In the determination of the moments of inertia of airplanes by swinging tests, the effect of the ambient air in increasing the apparent mass and moment of inertia must be estimated. Such estimates are chiefly based upon experimental data on the additional mass and moments of inertia of flat plates. During the past year it has been necessary to supplement previously estimated values of the moments of inertia of airplanes by data obtained from experiments with flat plates of tapered plan form. These experiments were conducted in a vacuum chamber and the results are now being prepared for publication.

MISCELLANEOUS TESTS OF MODELS AND AIRPLANES

A considerable number of requests have been received from the Army and the Navy during the past year for investigation of complete models of military airplanes and experimental airplanes of the fighter class in the Committee's wind tunnels. Most of the models have been investigated at the request of the military services; some models have been tested for manufacturers at their expense and other models have been built and tested in connection with the Committee's own research programs. The work has been carried out in the full-scale, the 20-foot, the 7- by 10-foot, and the 8-foot high-speed wind tunnels.

The greater portion of the time in the full-scale tunnel has been devoted to tests for the Army and Navy of complete models and single- and two-place airplanes of the combat type. The information obtained in the model tests has resulted in definite improvement of the design of the projected airplanes. The modifications made to airplanes in these tests have indicated substantial increases in the high speed, and these increases have been verified by flight tests.

Investigation of a model of a typical two-engine low-wing transport has been made in the 8-foot high-speed wind tunnel. The investigation has shown the contributions of various components of the airplane model to the total drag. The wing accounted for about 37 percent of the total drag; the fuselage, including interference, 25 percent; the nacelles, 11 percent; and the landing wheels with the main wheels retracted but partly projecting below the nacelles, 14 percent. The landing wheels even in the retracted position contributed a notably large percentage of the total drag. This drag could be eliminated by complete retraction. About 80 percent of the total landing-gear drag was due to the main wheels and the remainder to the tail wheel. The nacelles were the only part of the airplane exhibiting marked compressibility effects at speeds up to 450 miles per hour. The critical speed of the nacelles could have been increased to above 450 miles per hour by proper alinement with the air stream. The results of this investigation are now being prepared for publication.

Aerodynamic tests of five side-float models for seaplanes were made in the 7- by 10-foot wind tunnel and the results have been published in Technical Note No. 680. This investigation indicated that the most promising method of reducing the drag of these floats is to lower the angle at which the floats are rigged.

NATIONAL BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Wind-tunnel turbulence.—The great progress in the study of the practical effects of turbulence in wind tunnels as related to performance in flight carried out at Langley Field has shifted the interest from the effects of intensities of turbulence of the order of 1 percent to those of intensities of the order of 0.1 percent. As a result, it has been necessary to provide wind-tunnel equipment in which low turbulence levels can be obtained and to increase the sensitivity of the apparatus for measuring turbulence.

The modernization of the 4½-foot wind tunnel provided an air stream of low turbulence. Since this tun-

nel was first placed in operation in October 1938, numerous improvements have been made, each one successively reducing the turbulence of the stream, and further reductions are in prospect as the sources and behavior of wind tunnel turbulence are better understood.

The intensity of the turbulence is so low that its measurement presents some difficulties. However, by the use of a Wollaston wire about 0.00024 inch in diameter and 0.16 inch in length, sufficient sensitivity is obtained to measure intensities as low as 0.05 percent with reasonable precision. It is found necessary to use an antivibration support, and to modify the wire mounting to prevent vibration of the wire itself and to insure vibration of the mounting prongs as a unit when mechanical shock occurs.

The diameter of these small wires cannot be measured with sufficient accuracy to permit a computation of the time constant. Apparatus was constructed for experimental determination of the time constant. The method used is that of vibrating the wire with a fixed velocity amplitude but varying frequency in a stream of low turbulence. The vibrator is an electromagnetic pulsator and the velocity amplitude is measured by an electromagnetic pick-up device. Reproducible and accurate results are obtained.

The great progress in the development of electron tubes, the feed-back amplifier, voltage-stabilizing circuits, etc., has made possible for the first time the design of really portable equipment for measuring turbulence. With suitable hot-wire units, both longitudinal and transverse components of the fluctuations can be measured, as well as the correlation between longitudinal and transverse components. Construction of amplifier and power supply have been completed and their operating characteristics are under study. The design makes possible the use of the condenser-type compensating circuit, permitting a considerable reduction in the weight and size of this component.

A general account of turbulence investigations conducted for the Committee at the National Bureau of Standards was presented at the Fifth International Congress for Applied Mechanics.

Boundary-layer investigations.—A report entitled "Air Flow in the Boundary Layer of an Elliptic Cylinder" was published by the Committee as Technical Report No. 652.

The study of transition at low turbulence levels on a thin flat plate parallel to the wind direction has been in progress during the year. In view of the results of previous work, great care has been taken to have all factors which might affect the transition under control. The plate, which is made of aluminum and is ¼ inch thick and 12 feet long, is placed vertically between opposite faces of the octagonal working section of the tunnel. The leading edge was carefully machined to a lenticular form with a very thin edge. The pressure gradient is adjustable by means of flexible side plates on the two vertical faces of the octagonal test section, making in effect a channel on each side of the plate of adjustable width. The pressure could be adjusted to be constant within 0.05 percent of the velocity pressure.

A number of exploratory measurements of the location of transition as a function of various factors have been made. Contrary to expectation, the transition point is not unduly erratic or sensitive to small changes. Its location still depends markedly on the turbulence and erratic variations in its position obtained in other laboratories are probably due to erratic variations in the turbulence level. A value of the critical Reynolds Number of about 3,000,000 has been obtained for the condition of zero pressure gradient.

The work conducted for the Committee formed the basis of the Second Wright Brothers Lecture of the Institute of the Aeronautical Sciences.

AERONAUTIC-INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

Investigations.—A description of, and laboratory performance data on, the gyroscopic turn indicator, the directional gyroscope, the gyro horizon, the gyromagnetic compass, and a description only of the automatic pilot, are included in a report published as Technical Note No. 662.

A report on the theory and performance of modern rate-of-climb indicators has been published as Technical Report No. 666.

The investigation of corrugated diaphragms in progress included measurements of the central deflection against differential pressure of geometrically similar diaphragms of four diameters (1.5, 2, 2.5, and 3 inches) and a number of thicknesses in the range from 0.001 to 0.013 inch. The data were obtained principally on beryllium-copper and phosphor-bronze diaphragms and on a few diaphragms of Z nickel. These data have been analyzed and generalized into a mathematical formula. A report has been completed.

A sensitive diaphragm capsule has been developed which is prevented from deflecting above any desired differential pressure. At the cut-off pressure the diaphragms nest into each other. Two elements, consisting of two evacuated capsules, have been built for measuring air pressure in the range from 140 to 0 millibars. When used on a Diamond-Hinman radio sonde a sevenfold increase in sensitivity was secured in this pressure range.

The theory for the movement of a piston in a cylinder filled with liquid has been formulated in connection with an investigation of dashpots. To check the theory,

eighteen pistons were tested in cylinders of two diameters. Liquids of two viscosities were used. The piston clearance was varied from 0.0005 to 0.005 inch. Theory and experiment checked within ±10 percent. A report is being prepared.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The Subcommittee on Meteorological Problems keeps in contact with the progress of investigations being conducted by the various agencies on problems relating to atmospheric conditions which are of particular importance in connection with aircraft design and operation. The Special Committee on Lightning Hazards to Aircraft is organized under the Subcommittee on Meteorological Problems.

Atmospheric disturbances and their effect on airplane operation.—The Langley Memorial Aeronautical Laboratory has continued its study of gust intensities and gradients and their effect on airplane accelerations in flight. Additional records have been obtained on both military and commercial airplanes by means of N. A. C. A. V–G recorders, the total number of hours of flying time accumulated on commercial transports having been increased to 82,000. One incident of particular interest was reported in which a military airplane was subjected, without previous warning to the pilot, to an isolated strong gust of an intensity usually associated with that of severe thunderstorm conditions. In this gust the effective gust velocity was more than 30 feet per second.

The accumulation of data by means of V–G recorders has included operation over the principal air lines in the United States, on the routes from the East Coast to Bermuda and to the northern part of South America, over the Andes Mountains, and across the Pacific and the Atlantic.

From statistical data obtained on a number of airplanes it appears that the gust gradient distance is directly proportional to the size of the airplane and is approximately 8.5 times the wing chord length. By means of flights in thermal gusts to altitudes up to 17,000 feet, a correlation has been obtained between the gust velocity and various other factors, including the gradient distance, wind velocity, wind gradient, thermal energy, and altitude.

Lightning hazards to aircraft.—Data are being accumulated from air transport operators by means of a questionnaire on incidents of lightning strikes to airplanes, and an analysis of the information so far obtained has been made. It is of interest that, although there have been a number of instances of lightning strikes to airplanes, the resulting damage to the aircraft was slight, and in a large number of cases the passengers, and occasionally even the pilots, were not aware of the incident.

A study is being made at the University of New Mexico, under the cognizance of the Special Subcommittee on Lightning Hazards to Aircraft of the location and intensity of electrical charges in the atmosphere. Evidence obtained in this investigation indicates that discharges from cloud to ground are of a negative polarity. Investigations are being conducted in electrical research laboratories on the effect of electric discharges simulating lightning strikes on sheet metal of various types, particularly those used in aircraft construction. From information so far obtained it appears that it is possible to determine from the size of a hole caused by lightning in any given thickness of metal the amount of current involved. It is planned to accumulate from aircraft operators samples of burned metal removed from airplanes on which lightning strikes had been experienced and determine the amount of the current which caused the burn.

Careful consideration has been given to the specific hazards from lightning to various portions of the airplane such as radio equipment, gasoline tanks, fabric covering, control mechanisms, etc. It is believed that if suitable precautions are taken in all cases, the danger from lightning to an airplane in flight is slight. The avoidance in all cases of atmospheric conditions which indicate the probability of lightning is considered desirable, however, and instructions to this effect have been issued by one airline operator to its flying personnel, with material reduction in the number of lightning strikes experienced.

SUBCOMMITTEE ON SEAPLANES

The relative importance assigned to the various hydrodynamic problems connected with the design and construction of seaplanes, which are under the cognizance of the Subcommittee on Seaplanes, has changed radically during the past year. For several years the major hydrodynamic problem has been that of resistance, and the possibility of successfully getting into the air was considered to be largely determined by that factor. Today the major hydrodynamic problems appear to be (1) dynamic stability while in motion on the water, (2) spray, and (3) seaworthiness. This almost sudden change has come about because of the pressure on the designers of demands for extreme performance in the way of speed, range, and pay load. In the endeavor to produce hulls having minimum air drag and structural weight, the almost universal tendency has been to adopt forms having relatively narrow and deep cross sections.

This form also gives the familiar arrangement of the passenger accommodation in civil craft. But narrow hulls have meant heavily loaded hulls; the high position of wings and engines—and, in many cases, fuel—has caused the center of gravity of the whole

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craft to rise to surprisingly high positions; the heavily loaded wings and high air speeds have caused landing speeds to be considerably increased. As a result of these changes, the difficulties associated with obtaining adequate longitudinal stability (freedom from "porpoising"), freedom from excessive spray and from spray thrown into the propellers, and moderate impacts of the bottom on the water while landing and taking off have been greatly increased. At the same time, the use of engines with greatly increased horsepower available for take-off, because of the increased power needed for flight at higher speeds, and the general use of automatic or controllable propellers with greater efficiencies in the range of take-off speeds, have made the water resistance of the hull of much less importance in determining whether a seaplane can get into the air. This situation has made it necessary to broaden the scope of the Committee's work and to undertake the provision of additional facilities to enable adequate consideration of the new problems.

Apparatus and technique to conduct the investigations made necessary by the new problems have been developed and expanded as rapidly as possible. Equipment of a semi-permanent type has been constructed, and appropriate methods of operation have been developed for testing dynamically similar models of complete flying boats for the purpose of studying their dynamic stability. Methods of constructing the very special type of models required for this work have been devised. Accurate methods of ballasting the models so that the weight and the moment of inertia about the center of gravity will correspond to those of the full-size craft have been developed. The theory on which a mathematical study and a determination of the stability may be based has been investigated and a revised treatment, based on that of Perring and Glauert, has been begun. A sound theoretical treatment will be very helpful in the understanding of this very complex problem and in the direction of the broad fundamental research that must be carried out if the problem is to be solved.

With the limited equipment already at hand, it has been possible to investigate the dynamic stability of two specific machines for the Bureau of Aeronautics and of one for a private corporation.

Work for the military services of the Government has continued to receive first priority in the work of the tank. Four investigations of specific flying-boat projects and two investigations of novel devices have been completed. Several projects requiring the high towing speeds available only at the N. A. C. A. tank were completed for the Navy.

The fundamental researches completed and under way were of interest because of the use in several cases of large families of related models to study the influences of form on the hydrodynamic qualities and because the scope of the investigations was extended to include aerodynamic effects as obtained in parallel wind-tunnel tests on the same models.

Plant and equipment.—The efficiency of routine tests in smooth water has been increased by the installation in the tank of devices that damp out the surges caused by the operation of the carriage and by the perfecting of more durable wave suppressors. The development of these devices, as well as the design of a wave-making device, has been facilitated by the construction of a small tank one-eighth the cross section of the N. A. C. A. tank and 50 feet long. This tank has large glass panels in the sides and in it large models of the devices can be operated while the motions of the water about the models are observed.

Hulls for long-range flying boats.—In a long-range aircraft, small increases in air drag have a large influence on pay load and the best form of hull for such a craft presumably is one that approximates a streamline body and departs from such a form only by the amount required to give satisfactory hydrodynamic qualities. It is anticipated that the trend of design will be toward such forms, and both tank and wind-tunnel data are being accumulated to aid in their further development.

Technical Note No. 668 describes tests in the tank and in the 20-foot wind tunnel of two models of the planing type of hull, the forms of which are derived from a body of revolution and which represent extreme aerodynamic refinement as compared with existing hulls. The tank tests showed that the models were generally satisfactory but under certain conditions developed a tendency to behave unsatisfactorily. Take-off calculations for an assumed giant flying boat indicated that its take-off characteristics would be satisfactory if the trim was properly controlled. These models had lower air drag for the same volume than any models previously tested in the 20-foot wind tunnel. They also possessed the desirable characteristic of having smaller than usual increases in drag with departures from the angle for minimum drag.

It was apparent from the tank tests that there is in general no sharp line between good and poor water performance to determine the practical limits of aerodynamic refinement. A family of models has therefore been devised having systematic variations in the degree of departure from a streamline body. Tests of this family, now in progress, will provide further information on the best compromise between desirable aerodynamic and hydrodynamic qualities.

Outboard floats.—The best form of outboard float also represents a compromise between the requirements of low aerodynamic drag and satisfactory characteristics

on the water. As part of a program for the investigation of outboard floats, four models of typical floats were tested in the tank and in the 20-foot wind tunel (Technical Note No. 678). From the data obtained, the forms were compared on the basis of aerodynamic drag, spray, and yawing moments for given righting moments. Others factors, such as relative angle of heel, possible impact loads, and structural simplicity, were also considered in the analysis. It was concluded that the best form for an outboard float, when all its requirements are considered, is one having a transverse step for good planing characteristics and having its buoyancy distributed horizontally rather than vertically.

Tests of models of representative flying-boat hulls.—A one-sixth-size model of the hull of a Navy flying boat was investigated in the tank as part of the general program of tests of typical hull forms. This hull was a more recent adaptation of the NC type and was of special interest because of several features intended to improve take-off performance. These features included pronounced chine flare on both forebody and afterbody, a downward hook in the surface of the bottom at the step, and a tail extension shaped to provide additional hydrodynamic lift at low speeds. The hydrodynamic characteristics were found to be very satisfactory over a wide range of loadings and speeds. The results of the general test have been published in Technical Note No. 681.

In this publication a new type of chart was introduced for use in calculations of take-off performance based on the data from the general test. Since at a given speed, load and resistance are functions of the trim, the data are plotted in the form of resistance coefficient against trim with load coefficient as parameter. A number of such plots are made for a succession of speed coefficients such as would be used in a step-by-step calculation of take-off events. The curves of trimming-moment coefficient are superposed on these plots in the form of contours of constant trimming-moment coefficient. Experience with these charts has shown that they are preferable to the previous charts plotted against speed coefficient because of the greater ease of interpolation and the wider application to problems involving arbitrary conditions of trim or trimming moment.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

The problems of flutter and vibration, especially in the case of large fast airplanes, continue to be increasingly important. During the past year, two meetings of the Special Subcommittee on Vibration and Flutter and a special conference on these problems were held. At one of the meetings, the problem of flutter was discussed with representatives of the industry. The calculation of the flutter speed and the parameters necessary for its determination were considered, particularly with a view to the possible means of reducing the labor involved in making such calculations.

A special conference with manufacturers was held at Langley Field and considered the difficulties being experienced with propeller vibration. At this meeting, equipment for the study of the fundamentals of propeller vibration and damping was discussed. This equipment has now been completed and is ready for operation.

Most of the work on vibration carried out this year by the Committee has been related to the problem of flutter. In addition to the theoretical and experimental work on flutter, several projects on vibration have been undertaken because of their importance in relation to the problem of flutter.

Ground tests.—Vibration tests have been made on a number of airplanes on the ground. Equipment and methods have been developed to facilitate these measurements.

Damping tests.—The problem of determining values of structural damping for use in flutter calculations has been studied. Methods have been developed for separating the motions associated with different normal modes.

Model beams.—Exact solutions have been obtained for the equation of torsional vibration of a very general class of tapered beams (Technical Note No. 697). Tests on a set of tapered beams have been made and compared with theoretical results for both torsion and bending. These results indicate the effect of taper upon frequency for most cases of tapered wings.

Elastic airplane model.—A model of convenient size having elastic properties and weights distributed similarly to those of a typical modern airplane has been built. This model has been used in tests conducted to develop a technique of determining the various elastic, mass, and coupling parameters determining the flutter properties of the wing and the tail.

Flutter problem.—Flutter calculations have been continued during the past year. Particular attention has been given to the calculations for three degrees of freedom in order to determine more carefully when these can be replaced by the simpler cases for two degrees of freedom. The flutter parameters of several present-day airplane wings have been determined. A number of aircraft companies have cooperated by supplying information concerning the structural parameters.

The theoretical work on flutter has been extended to include the effect of aileron tabs and servorudders.

Further contributions to the flutter problem have been made through the study of unsteady-lift functions for wings of finite aspect ratio (Technical Note No.

682) and the experimental verification of the theory of oscillating airfoils (Technical Report No. 673).

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

INCREASE IN ENGINE POWER

The prime requisites for aircraft power plants at the present time, either for military or commercial service, are increased power for take-off and altitude operation, as well as greater economy in fuel consumption. Additional power is being striven for, principally through the development of fuels with higher antiknock values and increasing the effectiveness and number of the power strokes. The importance of the fuel work is indicated by the fact that improved fuels have contributed to a large extent in doubling engine power during the past decade. Further improvements in supercharging can be expected to provide materially higher intake manifold pressures and therefore greater power at altitude. Engine operating speeds are also being raised. The power requirements of the larger aircraft, exceeding as they do the capabilities of existing engine types, has led to the development of engines with more cylinders and consequently greater displacement. The thermal and mechanical limitations to achieving increased power centers principally on the cooling of the exposed parts in the combustion chamber and on carrying the loads imposed on the principal bearings. Fuel economy is now of the utmost importance, both because of its effect on the range of military equipment and on the operating expense of commercial aircraft. The greatest improvements in economy are anticipated from the reduction of power-plant and cooling-system drag and the recovery of waste heat. Renewed interest is being taken in in-line liquid-cooled power plants because of their small frontal area, while intensive work is going forward to provide minimum-drag cowlings for the radial air-cooled engine types and more efficient means of dissipating the heat in both air- and water-cooling systems. Savings of as much as 15 to 20 percent of the total airplane drag are possible by these means. The problem of waste heat recovery is particularly important, since only some 30 percent of the heat value of the fuel is utilized in the present-day power plants. The Committee is actively engaged in researches designed to provide practical solutions for many of these problems, as will be seen from the following report.

High octane number fuels.—In the development of aircraft engines it is becoming increasingly important that the engine designer know the effect of the different engine operating conditions on the maximum permissible engine performance. For this reason the Committee is conducting an investigation to determine the relationship between maximum permissible engine performance and the knocking characteristics of aircraft-engine fuels. This investigation is under the cognizance of the Subcommittee on Aircraft Fuels and Lubricants and is described in the report of that subcommittee.

Flow through engine inlet valves.—The results of the investigation of flow coefficients with intermittent flow through engine poppet valves have been published in Technical Note No. 701.

A sleeve valve and cylinder have been assembled for determining the flow coefficients of the inlet ports with pressure drops through the valve at values up to 8 pounds per square inch. Over-all flow coefficients have been measured with the valve operating as in an engine. Coefficients with the sleeve valve partly opened have been measured with the sleeve stationary, and the coefficients that apply to these partial openings have been checked against the over-all flow coefficients. A preliminary comparison shows the flow coefficients of sleeve valves to be the same for the partly opened valve as for the fully opened and operating valve. The coefficients derived from the test data are about the same as those obtained previously for the poppet valves.

Piston temperatures.—The investigation of the important factors controlling piston cooling and the effect of engine and cooling conditions on piston temperatures has been continued. The temperatures at five locations on a piston of an air-cooled engine have been determined for varying engine speed, load, spark advance, fuel-air ratio, head and barrel temperature, and oil temperature and viscosity. The data are being analyzed and will be prepared for publication.

Piston rings.—Piston-ring sticking, loss of tension, and wear are failures that limit the output of high-performance engines. An investigation is in progress to determine the engine-operating characteristics of superior cast-iron and nitrided-steel piston rings when operated in nitrided-steel liners. The use of piston rings of those materials and compounded lubricating oils have greatly reduced ring sticking and loss of tension. The problem of reducing the wear of piston rings in high-output engines is being studied.

Valve-overlap investigations.—The use of large valve overlap and increased inlet manifold pressure is an efficient method of removing the residual exhaust gases from an engine cylinder and of cooling the surfaces of the combustion chamber. The work on the single-cylinder test engine has been extended to a nine-cylinder radial spark-ignition engine equipped with an injection system spraying the fuel into the

cylinders. The engine was fitted with a special cam giving approximately 130° overlap between the open periods of the exhaust and the inlet valves. The poor idling of the engine experienced with large amounts of valve overlap was overcome by placing separate throttle valves close to the intake port of each cylinder. With these auxiliary throttles, the idling with large valve overlap was equal to the idling with the standard throttle and standard engine timing.

The 2-stroke-cycle engine.—Research has continued on the factors affecting the performance of the 2-stroke-cycle fuel-injection spark-ignition engine. The liquid-cooled engine used in this investigation is a uniflow type having scavenging and charging air admitted to the cylinder through piston-controlled inlet ports and exhaust through four poppet valves in the head. The factors investigated have included the number, the size, and the angle of the inlet ports and the lift and the timing of the exhaust valves. Investigations are in progress to increase performance by more effective breathing capacity and increased engine speed.

Recovery of energy in exhaust gases.—The conventional aircraft engines discharge as waste heat 65 percent of the energy of the fuel. Since the weight of fuel constitutes about half of the useful load of a long-range airplane, it is extremely important that methods be developed for utilizing a part of this waste energy. An analysis has been made of the energy recoverable by methods that require no additional prime movers but depend on the forward motion of the airplane. The pressure variation attending the flow of cooling air through the duct of the cooling system provides a convenient thermodynamic cycle for recovering waste heat. Thrust is obtained from the increased velocity of the cooling air as it leaves the duct exit.

The power recoverable by this method has been calculated for three conditions: first, for the normal duct radiator; second, for the duct radiator having the heat in the exhaust gas transferred to the cooling air in the duct; and third, for the duct radiator having the exhaust gas discharge into the duct. The effect of a fan in the duct for increasing the compression ratio of the thermodynamic cycle has been considered. A report is in preparation covering the results of this investigation.

Jet reaction as take-off aid.—The possibility of using auxiliary jet propulsion for aid during the take-off has been analyzed and compared with the use of larger engines. The analysis shows that the weight of fuel and liquid oxidant required for an appreciable improvement in take-off performance is sufficiently small to indicate that serious consideration should be given to this method of assisting the take-off when take-off aid becomes necessary. A report based on this analysis is being prepared for publication.

COMBUSTION RESEARCH

Knock investigation.—The construction of the N. A. C. A. high-speed motion-picture camera was completed during the past year. With this camera motion pictures can be taken at rates up to 40,000 photographs per second, whereas previous pictures had been taken at speeds of 2,400 pictures per second. Projecting these motion pictures at speeds of 16 photographs per second gives the effect of increasing the visual speed of the observer 2,500 times.

The motion pictures of combustion obtained with the new camera and the N. A. C. A. combustion apparatus have made possible a detailed study of the combustion process. Throughout this investigation, schlieren photographs have been taken because past experience has shown them to be superior to the usual flame photographs. When knock occurs in the engine, the photographs show that the phenomenon is completed in from 0.00005 to 0.00010 second. The photographs emphasize the fact that knock appears to be a much different phenomenon from the normal combustion which precedes the knock. The actinic value of the knocking flame is many times that of the flame previous to knock. With severe knock, a preknock reaction in the end gas, which has been previously observed, is clearly shown.

The results of the investigation made to determine the effect on air movement within the engine cylinder of several arrangements of shrouded intake valves have been published in Technical Report No. 653.

An investigation of the effect of air flow within the combustion chamber for spark-ignition engines on the propagation of combustion has been reported in Technical Report No. 657.

Preignition characteristics of fuels.—The N. A. C. A. combustion apparatus has been used to investigate the preignition characteristics of aircraft-engine fuels. For the purpose of these tests preignition of the fuel was caused by an electrically heated coil located in the combustion chamber. The temperature of the coil was measured by a thermocouple. Fuels included in the investigation were iso-octane, benzene, toluene, methyl alcohol, and different fuel blends. In general, the results have shown that the preignition temperature is not greatly affected by engine speed or compression ratio. The preignition temperature remains fairly constant as the fuel-air ratio is decreased from a rich mixture until the mixture approaches that for complete combustion of both fuel and air. Any further leaning causes a sharp increase in the preignition temperature. The results have shown that there is no general relation between the knocking characteristics and the preignition characteristics of a variety of fuels. The results of this investigation are being prepared for publication.

Engine charge temperature.—An investigation has been undertaken of the heat-transfer process during the intake and compression strokes of an internal-combustion engine in order to facilitate a study of knock in aircraft engines. Indicator diagrams have been obtained on a Wright 1820–G single-cylinder test engine, from which the engine charge temperature at the end of the induction and compression strokes has been computed. The variation of charge temperature with engine speed, throttle setting, air-fuel ratio, inlet-air temperature, and cylinder-wall temperature has been determined.

Air flow in engine cylinders.—For fuel injection into the cylinders of an aircraft engine, it is necessary that an air swirl be produced in the cylinder or that a high degree of air turbulence exist to assist in distributing the fuel spray. The investigations to determine the effect of inlet-port and valve design on the air movement within the cylinder of an internal-combustion engine have been continued. Two cylinder heads simulating air-cooled engine practice were constructed and tested on the glass-cylinder engine. In both cases the air movement was partly controlled by the design of the intake port in the cylinder head. With one arrangement the air rotated about the cylinder axis and with the other a vertical swirl was produced. Both designs were effective in giving good engine performance. The results are being prepared for publication.

FUEL CONSUMPTION

Fuel distribution.—The results of the investigations made to obtain a comparison of the performance of an engine with a carburetor, with fuel injection into the inlet manifold, and with fuel injection into the cylinder have been published in Technical Note No. 688.

Increase in compression ratio.—Modern aircraft engines operate at compression ratios of from 6.0 to 7.5. An appreciable reduction in fuel consumption may be obtained by operating at higher compression ratios. An investigation is in progress on a single-cylinder engine to determine the improvement in power output and fuel consumption to be obtained with an air-cooled cylinder having a displacement of 200 cubic inches when operated over a range of compression ratios from 7.4 to 10.2. The fuel is injected into the engine cylinder. At a compression ratio of 9.2 and with atmospheric intake pressure, a brake mean effective pressure of 182 pounds per square inch was obtained at 1,750 r. p. m. The corresponding brake fuel consumption was 0.356 pound per brake horsepower-hour.

Fuel economy in flight.—Military operation often requires flight speeds at or near the maximum. As the maximum power condition of an airplane engine is approached, sacrifices in fuel economy must be made to avoid overheating and detonation. It is important that the fuel consumption be kept as low as possible consistent with safe operation, since the fuel load is a large part of the disposable load of the airplane. An analysis has been made of the methods of increasing power for maximum fuel economy, with detonation and cylinder temperatures as limiting conditions. The results of the analysis showed that the least hourly fuel consumption is obtained at the lowest practicable engine speed and with an approximately correct mixture. Starting from these conditions the methods of increasing power in the order of fuel economy were shown to be:

(a) Increasing manifold pressure at constant minimum practicable engine speed to the point of incipient knock or to full throttle if knock is not encountered.

(b) Increasing engine speed and maintaining constant cylinder temperatures by cooling within knock limits until maximum engine speed is reached.

(c) Retarding the spark or reducing the cylinder temperatures to permit higher manifold pressures.

(d) Increasing the fuel-air ratio to permit higher manifold pressures.

A report has been prepared covering this material.

Safety fuels.—Renewed interest has been shown in the use of new safety fuels having the same heating value as gasoline and relatively good antidetonating qualities. The flash point of these fuels is about 115° F., which should result in an appreciable reduction in the fire hazard when used in aircraft. The preliminary tests made with one of these safety fuels having a distillation range from 325° to 425° F. showed that in a single-cylinder engine fitted with a modern air-cooled cylinder the power and fuel consumption are equal to that obtained with gasoline having the same antidetonating qualities.

ENGINE COOLING

Cooling of finned cylinders.—A report has been published (Technical Report No. 674) covering an investigation of the cooling on the front of an air-cooled engine cylinder. The results show the relative effect of various operating conditions and fin dimensions on the cooling of a finned cylinder in a conventional cowling. An analysis of the cooling problem on an air-cooled engine has been made to show what may be done to improve the cooling and what each improvement requires in increased power expended for cooling. Cooling at altitude was also studied, as well as the relationships between indicated horsepower, cooling requirements, and cooling on the ground.

Fin dimensions.—The analysis to determine the proportions of aluminum, copper, magnesium, and steel fins necessary to dissipate maximum quantities of heat for various fin widths, fin weights, and air-flow conditions has been completed. The analysis includes the

determination of the optimum fin proportions when specified limits are placed on the fin dimensions. In addition to the information presented on the design of fins, this investigation shows that optimum fin dimensions are not appreciably affected by the differences in air speed obtained with different air-flow arrangements or by small changes in the length of the air-flow path. For a given fin weight, the highest heat transfer can be obtained with fins of a magnesium alloy; pure copper and aluminum-alloy fins are only slightly inferior to magnesium-alloy fins and will dissipate several times more heat than steel fins. The results of this investigation have been prepared for publication.

Heat-transfer coefficients.—The investigation to determine the surface heat-transfer coefficients of finned cylinders has been completed and the results have been published in Technical Report No. 676. The investigation covered the determination of the effect of fin width, fin space, fin thickness, and cylinder diameter on the heat transfer. Wind-tunnel tests were made in a free air stream with and without baffles and also with various devices for creating a turbulent air stream. Tests were also made with blower cooling. Correlation of the surface heat-transfer coefficients measured on 58 finned cylinders was found possible by plotting factors including the air-stream characteristics and the dimensions of the finned cylinders.

Heat-transfer process.—A report has been prepared covering the heat-transfer process in a Wright Cyclone engine. Equations for the cylinder head and barrel temperatures as functions of the important engine and cooling conditions are given. A method of correlating and comparing cooling data is presented and is illustrated by curves obtained from data on multicylinder engines in flight and on the test stand, and from single-cylinder test data. The distribution of temperature around the cylinder head and barrel and the correlation of temperatures at individual points on the cylinder are discussed. Calculated curves are presented showing the variation of cylinder temperature with altitude in climb and level flight. Data are also presented showing the variation of cylinder head and barrel temperatures with time when the throttle is suddenly opened and when the cooling air speed is suddenly decreased.

Heat-transfer coefficients in flight.—Apparatus has been installed in an airplane and several tests made to determine the surface heat-transfer coefficients of an electrically heated finned cylinder in flight. The object of these tests is to determine heat-transfer coefficients in flight and compare them with those obtained in the laboratory.

Single-stage axial-flow fan.—Calculations have been made for a single-stage axial-flow blower to determine its suitability for cooling airplane engines. Pressures in the neighborhood of 10 inches of water appear to be attainable with efficiencies of more than 80 percent. A fan of this type seems to be suitable for large present-day engines. Although some installation problems have been encountered, they do not seem to be insurmountable, especially for the large radial engines having more than one row of cylinders.

The N. A. C. A. air-cooled cylinder.—The method developed by the Committee for bonding preformed aluminum-alloy fins to the cast aluminum-alloy air-cooled cylinder heads has permitted a large increase in the power output that can be obtained from a cylinder having a given displacement. Two air-cooled cylinders have been constructed having the fins attached by this method and the performance of the cylinder has been determined on a single-cylinder engine. The cylinders have the same internal dimensions as a conventional air-cooled engine cylinder but five times the fin surface. For the same power output and same cylinder temperatures, the amount of air required for cooling the N. A. C. A. cylinder is only 35 percent of that required to cool the conventional cylinder. For the same pressure drop across the cylinders, 15 inches of water, and the same cylinder temperatures, it is possible to obtain nearly three times the power from the N. A. C. A. cylinder as from the conventional cylinder.

Preliminary tests showed that satisfactory cooling could be obtained on the N. A. C. A. cylinder with a pressure drop across the cylinder of only 2 inches of water when operating at an engine speed of 2,100 r. p. m. and a boost pressure of 5 pounds per square inch.

SUPERCHARGER RESEARCH

Performance of superchargers.—The computations on the performance of superchargers having a range of compression exponents from 1 to 2 and operating at altitudes from 0 to 80,000 feet over a wide range of boost pressures are being analyzed. The application of these results to the engine shows that if a geared centrifugal supercharger is used to maintain sea-level pressure to an altitude of 50,000 feet the fuel consumption will be twice that at sea level. This increase is due to the large amount of power required by a gear-driven supercharger. With the turbosupercharger there is no large increase in fuel consumption because the energy to drive the supercharger is taken from the exhaust gases. This analysis will be continued to include the application to engines of high compression ratios.

Air intercoolers.—The problem of increasing the antiknock value of fuels by air intercoolers includes the important consideration of the power necessary to force both cooling air and engine-charge air through the intercooler and also the power required to carry the weight added by the intercooler. A theoretical and experimental investigation is being made of a light-

weight type of intercooler that is expected to reduce charge temperatures materially with relatively low-pressure drop across the intercooler. A test unit of this intercooler is being constructed for laboratory testing.

Programs of investigation have been completed on radiator design and installation and on intercooler design for aircraft. Tests are being continued on tube banks in order to obtain more information on the detached mechanism of heat transfer and friction loss.

Engine power at altitude.—The calculation of flight performance at altitude is dependent upon the accurate determination of the variation in engine power with altitude. Several different formulas are available in the literature for correcting engine power at sea level to altitude conditions. A comparison has been made between the calculated engine power and the power as measured on an air-cooled engine in flight by use of the N. A. C. A. torque meter. The range of altitudes covered was from sea level to 20,000 feet. The engine power as measured by the torque meter checked the power as corrected for temperature and pressure by the use of well-established formulas. The results of this investigation and of a study of the variation of engine power with altitude are being prepared for publication.

COMPRESSION-IGNITION ENGINES

Combustion research.—The performance of high-speed Diesel engines is less than that of the conventional Otto-cycle engine because of the inability of the Diesel engine to burn efficiently the total air charge inducted into the cylinder. As a result, the Diesel engine requires a higher boost to obtain the same take-off mean effective pressure than does the spark-ignition engine. Apparatus has been assembled that will permit an extensive survey to be made of the mixture during combustion in a Diesel engine. Heretofore, such an investigation has been of doubtful value because it required several engine cycles to obtain a large enough sample of the mixture to analyze. The development of an industrial microanalyzer capable of analyzing volumes as small as $\frac{1}{20}$ milliliter has made it possible to collect an adequate sample from a single cycle. For this purpose a hydraulically operated gas-sampling valve has been developed that, during an opening period of 0.0004 second, will collect a sufficiently large sample from a predetermined section of the combustion apparatus.

A report has been prepared and published as Technical Note No. 707 presenting results of engine performance tests of fuel oils, mixtures of fuel oil and alcohol, and fuel-oil dopes.

The results of the investigation of ignition lag of Diesel oils as determined in a bomb and in an engine have been published in Technical Note No. 710.

Fuel-injection systems.—Previous investigations with a simulated unit injection system have demonstrated certain advantages for this type of injection system over the more conventional type in which a length of tubing connects the injection pump to the injection valve. For this reason, a unit injector has been tested to determine the effects of the various operating variables on the rates of fuel discharge. It has been found that, when an outwardly opening injection nozzle is used, the rates of fuel injection closely follow the rate of fuel displacement by the pump plunger. Under very high injection pressures, however, the compression of the fuel in the injection system causes the rate of discharge to be less than the rate of plunger displacement. Secondary discharges are eliminated when a unit injector is used and higher rates of discharge are obtained than are practicable with the injection pump mounted at some distance from the injection valve. The results of this investigation are being prepared for publication.

The 4-stroke-cycle engine.—The N. A. C. A. displacer-type combustion chamber has been adapted to an air-cooled cylinder having a 5-inch bore and a 5½-inch stroke. From the results of single-cylinder engine performance tests, multicylinder engine performance has been computed. On the basis of the weights of the single-cylinder parts, the weight of a nine-cylinder radial engine has been computed. These computed values indicate a specific weight of 1.6 pounds per horsepower for an output of 500 horsepower. From the results of single-cylinder tests, heat loss, heat-loss distribution, and cooling measurements have been calculated. An investigation has been started to determine the air-charging restrictions peculiar to the displacer-piston type of combustion chamber.

The 2-stroke-cycle engine.—The liquid-cooled engine used in this investigation has piston-controlled inlet ports directed at 56° to the radial, and exhausts through four poppet valves in the head. Engine-performance tests have been made with various rates of injection and various fuel-spray orifices in two diametrically opposed fuel valves, each valve injecting downstream with the rotating air flow. Tests have been made with reduced inlet and exhaust time areas to determine the amount of power reduction and exhaust characteristics. Preparations have been made to improve the air charging by using four rows of inlet ports and to increase power by increasing the engine speed to 2,400 revolutions per minute.

The 2-stroke-cycle sleeve-valve engine.—Analysis has shown that the single sleeve-valve mechanism should give better breathing capacity and higher allowable rotative speeds than the Committee's poppet-valve engine. With the object of determining engine-performance characteristics, a design has been completed

of a single sleeve-valve engine. The necessary parts for the test engine are now under construction by the contractor.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—A large number of photographs of explosions in a 10-inch spherical bomb were taken through a narrow window which formed a part of the bomb wall. In addition to the flame trace, each record contained a time scale in thousandths of a second and six points on the time-pressure curve. Mixtures of the fuels benzene, normal heptane (zero octane number), and iso-octane (100 octane number) with oxygen and nitrogen were studied. A technical report giving the detailed experimental results and the conclusions which have been drawn for the three hydrocarbons as well as those for previous measurements with carbon monoxide is being prepared for publication.

In all the explosions there is a general increase in the transformation velocity as the temperature and pressure of the unburned charge rise because of the adiabatic compression. Since the range of initial conditions was wider for carbon monoxide, it was possible to analyze these results for the independent effects of temperature and pressure, and both were found to contribute to the increase in transformation velocity. For the hydrocarbons in comparable mixtures, the transformation velocity is highest for benzene and lowest for iso-octane, with heptane intermediate. The addition of tetraethyl lead to the heptane mixture produced no appreciable change in flame speed. Thus, under the conditions of the experiments there appears to be no relation between transformation velocity and the tendency to knock.

Until the late stages of the explosion there is no measurable difference among the hydrocarbon fuels in the pressure rise produced when a given fraction of the charge is inflamed. For all the explosions the rise in pressure for a given mass of charge inflamed is considerably less than would be expected from calculations based on thermal data and the assumption that reaction goes to equilibriun in a very thin flame front. The results therefore indicate that the liberation of energy continues for some time after the flame front has passed. Observations of the gas movements within the sphere of flame, made by following the bright trails left by burning particles of gunpowder suspended in the mixture, also indicate the existence of continued reaction within the inflamed gases.

Since no connection could be found between any of the characteristics of the normal burning of the hydrocarbon fuels and their relative tendency to knock in an engine, a supplementary study of the influence of various factors upon the transition from normal burning to detonation has been undertaken. Construction of apparatus for this purpose was begun, while preparations for a series of measurements in the spherical bomb on triptane (2, 2, 3–trimethylbutane) were being completed.

Flow characteristics of fuel lines.—In connection with a cooperative attack on aviation vapor-lock problems, the Bureau has investigated the resistance to fuel flow in fittings and accessories of ½-inch tubing and in ⅝-inch tubing as a function of rate of flow and relative amounts of liquid and vapor flowing. The resistance of any fuel-system component to liquid flow is approximately doubled when equal volumes of liquid and vapor are present. It has been demonstrated that the resistance of conventional elbows can be reduced materially by redesign of the fitting, and a simple type of pressure tap has been developed which is suitable for general use, particularly in fuel system mock-ups.

Engine testing.—A study of the characteristics of oils and their effect on engine condition was made at the request of the Matériel Division of the Army Air Corps. The tests consisted of a series of 50-hour endurance runs on a 9-cylinder air-cooled engine mounted on a rigid stand.

Altitude tests were made on an aircraft auxiliary power plant for the Bureau of Aeronautics, Navy Department. Altitude tests on stationary power plants for beacon lighting, teletype, and other airway equipment were made at the request of the Civil Aeronautics Authority.

Temperature surveys.—Ground and flight temperature surveys have been continued on all new types of Navy aircraft engines. These include cylinder, oil, and intake-mixture temperatures.

Spark plugs.—A method of bench testing mica spark plugs has been put into service use with satisfactory results. Further investigation into materials and designs of spark plugs to meet the more exacting requirements of commercial and military services is under way.

Aircraft-engine cylinder wear.—An investigation was made to determine the cause of cylinder wear, particularly on the rear wall. From the data obtained for two continuous 50-hour runs on an air-cooled single cylinder engine, it was found that wear on the rear wall was caused chiefly by corrosion. Factors in the acceleration of the corrosion were the anti-knock compound used, the lubricant, and the temperature distribution of the cylinder.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Investigation of antiknock characteristics of fuels.—The investigation of the relationship of engine operating conditions to the antiknock characteristics of fuels has been continued. From the results obtained with a flat-disk combustion chamber and a pent-roof combustion

chamber an analysis has been made in which the maximum permissible engine performance under a variety of engine operating conditions has been derived from an experimental determination of the maximum permissible performance under a few conditions. The analysis shows that, from considerations of knock, the most important independent variables in any one engine are the inlet-mixture density and temperature and the mixture ratio. The data show that preignition must be treated separately from knock if fuels are to be adequately rated in an engine.

The analysis shows that, for any particular fuel, the maximum permissible power increases as the compression ratio is decreased, provided that the inlet air temperature is maintained constant and the performance is limited by knock and not by preignition. For cases in which the inlet air is heated an increasing amount as the boost pressure is increased, an optimum compression ratio exists for the engine from the consideration of maximum permissible power. The data show that a certain amount of correlation is possible between the curves of knock characteristics of several fuels from tests on different engines, but that certain differences are caused by engine design. The results of this investigation have been published in Technical Report No. 655.

A portion of the investigation has been completed on the determination of the knock characteristics of a cylinder with a semispherical combustion chamber. Although in general the results are the same as those obtained from the flat-disk and pent-roof combustion chambers, certain differences in the correlation of the data result from the difference in cooling characteristics of this engine. This investigation is being continued.

Additional tests of fuels are being conducted on a high-speed C. F. R. engine. With several fuels of 100 octane number used in this engine, different values of highest useful compression ratio were obtained as the inlet-air temperature was varied. The results also indicate that the effect of engine speed on maximum permissible performance may be a temperature effect resulting from the transfer of heat from and to the incoming mixture rather than being a time effect as has been previously suggested.

Investigation to develop nonleaded aircraft fuel of over 100 octane number.—This investigation, carried on by the National Bureau of Standards for the past two years in cooperation with the National Advisory Committee for Aeronautics, the Army Air Corps, and the Bureau of Aeronautics of the Navy Department, has been in a confidential status until recently. The program calls for the preparation of branched-chain paraffin hydrocarbons in the volatility range of aviation gasoline, and the investigation of their knocking tendencies and their physical properties.

Two automatically controlled fractionating columns were designed and installed for this work. Both columns have efficiencies of at least 100 theoretical plates and operate, practically without attention, day and night, Sundays and holidays, barring an unexpected failure of the electric power supply. These columns serve to separate and purify synthetic products and to isolate materials from industrial crudes. The project has required the construction of Grignard reactors, hydrogenators, and other necessary equipment for organic synthesis.

One of the first hydrocarbons prepared in this laboratory was 2,2,3–trimethylbutane, also called triptane, preparation of which was begun June 1, 1938. As the fractionating columns had not been completed at the time, this material was not finally purified until early in 1939, shortly after an industrial laboratory had reported that triptane was well over 100 octane number. When the Bureau's final product was blended with an equal volume of 90 octane reference fuel (90 percent iso-octane and 10 percent heptane) the octane number of the blend was over 99, indicating pure 2,2,3–trimethylbutane to be about 108 ASTM octane number. Six liters of this compound were supplied to the Langley Memorial Aeronautical Laboratory for further tests.

All the pentanes, hexanes, heptanes, and octanes of interest are now on hand. Three nonanes have been isolated from a synthetic crude and partially purified. Synthesis of two additional nonanes, one of which has been prepared once before and one never before, is in progress. Between one and two pounds of a solid octane have been recovered as a byproduct of the synthesis of other materials. This melts at 101° C. and boils at 106° C., and is very soluble in liquid paraffin hydrocarbons.

A study is being made to find a suitable scale for rating pure compounds which have octane numbers above 100. Various methods of extrapolation by means of an engine characteristic such as compression ratio on manifold pressure have been considered. However, the best proposal appears to be the use for the present of heptane and iso-octane, each containing 0.1 percent tetraethyl lead, as the primary reference fuels. Secondary reference fuels, one of which is technical iso-octane, also containing 0.1 percent tetraethyl lead would be calibrated against the primary scale and used in testing. This choice of a primary scale is dictated by the consideration that such a scale, composed of pure compounds, can always be duplicated and hence the ratings can in the future be translated into any other scale subsequently adopted merely by

intercomparison of the two sets of scale constituents. Experimental work on this proposed scale is in progress.

Stability of aviation oils.—Last year a laboratory test for oil stability was developed at the National Bureau of Standards and mentioned in the report as in satisfactory accord with changes taking place in the oils during service operation of aircraft engines. This correlation was subsequently extended to include all available information on engine deposits both in service and in test-stand operation. It appears that it is possible by means of a simple laboratory test method to predict not only the extent of the changes which will take place in an oil during service operation in aircraft engines but also to predict the extent of deposits which are formed in these engines.

For the information of the military services, a survey has been started on the stability characteristics of commercial aviation oils and it is planned to keep this survey up to date as new or improved aviation oils are developed.

Through the cooperation of the Research Committee on Aircraft Engine Lubricants of the Society of Automotive Engineers, a set of engine inspection forms has been developed for recording the condition of aviation engine parts at the time of overhaul with particular reference to those parts on which deposits form and to those parts in which differences in lubrication characteristics of the oil are important. This makes it possible for all observers to record data on engine conditions on a uniform and comparable basis.

Ring sticking with aviation oils.—Further information has been obtained at the National Bureau of Standards on the thickening of oils at the high temperatures encountered around the upper piston rings, and a simple laboratory test method has been developed which has significance as regards the tendency of oils to cause cold ring sticking. During the course of the extensive engine inspections undertaken in connection with the oil stability program, information was obtained regarding the extent of ring sticking. Comparison of the laboratory and engine data on these oils showed that the laboratory data correlated satisfactorily with the extent of ring sticking in service.

The conclusions reached in the investigation of oil stability and cold ring sticking favor highly solvent refined lubricating oils and work is under way to provide protection against serious difficulties with hot ring sticking and with excessive engine wear which may result if over-refined oils are used. It is expected that suitable test methods of protection against the use of over-refined oils will be available during the coming year.

Corrosion.—A new laboratory method of determining the corrosiveness of oils has been developed. It has been determined that corrosion due to oil in engines is critically affected by the preparation of the sliding surfaces during manufacture.

Bearing corrosion.—Considerable progress has been made at the National Bureau of Standards in the investigation of the problem of the corrosion of master-rod bearings. The general trend of the investigation has been to evaluate the critical temperatures at which oils form corrosive acids, and marked differences have been found between various oils in this respect. This work is rapidly approaching the stage where a significant laboratory test method can be proposed.

In the course of the corrosion work, it was found that there were appreciable differences between the results obtained by different laboratories in the determination of the neutralization number of used aviation oils. Accordingly, through the cooperation of the Research Committee on Aircraft Engine Lubricants of the Society of Automotive Engineers, a modified method for the determination of neutralization number was developed which was found to give reproducible values in different laboratories. A description of this method has been published by the American Society for Testing Materials in its annual report.

Lubrication of master-rod bearings.—A small bearing machine has been developed at the National Bureau of Standards for the investigation of master-rod bearing lubrication under severe operating conditions. This machine uses four small bearings similar metallurgically and in surface composition to full-scale bearings. It is possible to operate the machine over a wide range of speeds, loads, and oil temperatures. Information thus far obtained indicates that the machine is very satisfactory and that the load-carrying capacities of bearing materials can be rapidly and accurately evaluated.

REPORT OF COMMITTEE ON AIRCRAFT MATERIALS

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

Effect of continuous weathering on aircraft metals.—Aircraft structural parts built up of sheet-metal members are used very extensively. The development of the monocoque or stressed-skin type of airplane structure has served to emphasize strongly the importance of the durability of sheet metal. The effect of continuous exposure to weathering action is a factor which must always be considered.

Technical Report No. 663, "The Weathering of Light Metal Alloys Used in Aircraft," has been published.

This summarizes the results of extensive outdoor exposure tests of 5 years' duration previously carried out on aluminum and magnesium alloys in sheet form, of various commercial compositions and with various types of protective surface treatments and applied coatings.

A report is being published which summarizes the results obtained during the first year in the current series of exposure tests on aircraft metals. This covers aluminum and magnesium alloys and stainless steel, all in sheet form. In one series of tests the materials are exposed continuously in a marine atmosphere, Hampton Roads Naval Air Station, and in a supplementary series the materials are so placed as to be immersed in sea water at high tide. In these exposure tests emphasis has been placed on the determination of the effects on various types of metals when in contact one with another in both riveted and welded joints.

This series of tests, which was planned to extend over a period of several years, is an "open" one in that new materials of promise can be included as they become available. At the request of the manufacturers, an aluminum alloy, the commercial standing of which had been established by usage over a number of years, was included in the test, and arrangements are in progress for the inclusion of a recently developed material of unusual promise, although it is not yet commercially available. Only by prolonged exposure tests of this kind can the merits of such materials for aircraft use be established.

Elastic properties of high-strength constructional aircraft metals.—Technical Report No. 670, Tensile Elastic Properties of 18–8 Chromium Nickel Steel as Affected by Plastic Deformation, has been published. A second report entitled "Tensile Elastic Properties of Typical Stainless Steel and Nonferrous Metals as Affected by Plastic Deformation and by Heat Treatment," is being prepared for publication. This report considers the tensile elastic properties of 18–8 chromium-nickel steel, 13–2 chromium-nickel steel, monel metal, Inconel, and K-monel metal. A general discussion is given of the relationship between stress, strain, and permanent set. Stress-strain relationships are discussed, together with the variation of proof stresses with prior plastic extension; also the influence of work-hardening and internal stress on the form of the proof stress-extension curve. From the stress-strain curves have been derived stress-modulus lines. For all but relatively soft metals, the stress-modulus line is practically straight. Stress deviation, that is, deviation from stress-modulus line, and stress-set curves were determined, and from these were derived various diagrams illustrating the influence of plastic-extension and heat treatment on the elastic strength, on the modulus of elasticity, and on its stress coefficient. Equations have been developed to represent the form of the elastic stress-strain curve.

The next phase of the investigation, the study of the elastic properties at low temperatures (−108° F.) is being started. Steel of the 18–8 chromium-nickel type, the properties of which have already been studied at normal temperature, is the material to be used in this phase of the work.

Structural changes in aircraft metals occurring as a result of service.—Service stresses of structural members are, in general, largely of the character known as fatigue stresses. In this investigation, the study of the impact resistance of the metal after it has been subjected to fatigue stressing occupies an important place.

A report entitled, "Effect of Service Stresses on Impact Resistance, X-ray Diffraction Patterns, and Microstructure of 25S Aluminum Alloy," has been published, based on a study of the 25S aluminum alloy used extensively for propellers. No outstanding detrimental effects in this material attributable to fatigue stressing were observed.

The second phase of the investigation deals with the impact properties of normalized SAE X4130 steel (0.30 C, 1.00 Cr, 0.20 Mo) after fatigue stressing below the point at which incipient failure can be detected. Tensile impact tests of smooth unnotched specimens after being fatigued-stressed by axial loading have shown: (a) only slight difference in the tensile impact behavior of normalized X4130 steel at −32° C. and at +25° C.; (b) the production of nonductile impact fractures after sufficient numbers of cycles of stress above the fatigue limit; (c) a surface condition of marked significance—microscopic surface ruptures opened by the tensile impact stress, relatively few in number on highly polished fatigue specimens but present in large numbers on specimens for which a slightly coarser polish was used; (d) the fact that removal of a thin surface layer from fatigue-stressed specimens containing these surface ruptures restored their impact resistance to that of similar unstressed (undamaged) specimens, thus indicating that the damage revealed by the check cracks produced by tension-impact is confined to the surface zones. Further work on this subject is in progress.

Transverse impact tests of notched fatigue specimens prestressed in a rotating cantilever-beam fatigue machine showed that the impact resistance of notched specimens at −78° C. was generally one-half to one-fourth of that at normal room temperature, the percentage decrease in low-temperature impact resistance resulting from fatigue being greater than in similar tests at room temperature.

The extent to which a metal structure recovers during periods of rest following intermittent periods of fatigue-stressing is questionable. Definite indication has been obtained of the strengthening of normalized X4130 steel by alternating stressing above the fatigue

limit and resting. A series of rests and runs of rotating-beam fatigue specimens stressed above the fatigue limit resulted in conditioning the specimens so that after a while the specimen could be kept running continuously at the same overstress without further resting. This subject is being studied at greater length.

Protection of magnesium alloys.—Marked advance has recently been made in the development of new protective coatings for magnesium alloys. Five are now commercially available which are equal in the corrosion protection which they give to that produced by the anodic treatment in the dichromate-phosphate solution which has hitherto been standard. The improved treatments all involve a final sealing treatment. Only the methods based on anodic treatment, however, are applicable to all types of magnesium alloys. The use of hydrofluoric acid, which is an essential feature of some of the new treatments, is objectionable for several reasons in the practical application of the coatings, and efforts are being continued to eliminate its use.

Effect of subzero temperatures on aircraft metals.—The fact is well established that the lowering of the impact resistance of metals at low (subzero) temperatures is the most marked change in the properties of a metal structure which should be guarded against. In cooperation with the Bureau of Aeronautics, Navy Department, the investigation of various heat-treatment methods to improve this condition at low temperature has been continued, but so far without complete success. Indications have been obtained that certain heats of steel are consistently superior to other heats of the same nominal composition but the underlying factors are as yet not clearly understood. The impact resistance at normal room temperature is no criterion of this property at subzero temperature. In the case of welds the seriousness of this condition of low impact resistance at low temperatures is augmented by defects incidental to variations in welding technique. The investigation is being continued.

Commercial aircraft steel tubing.—In cooperation with the Bureau of Aeronautics, Navy Department, extensive tests have been carried out in seamless steel aircraft tubing (chromium-molybdenum steel, SAE X4130) obtained from all the available domestic sources of supply. Differences of considerable magnitude in the ultimate tensile strength and the yield strength as compared with the requirements set forth in the specifications of the Navy Department for this type of material were found, this being true for practically all of the manufacturers represented. These differences are apparently the results of differences in fabrication and heat-treatment procedures, since they could be practically eliminated by annealing. A change in the specification requirements may be the logical outcome.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The work of this subcommittee during the past year has been devoted chiefly to the development of plastic material for aircraft structures. A considerable amount of work has also been done on a continuation of the study of flexible transparent window materials, on the compilation of information about acoustical and thermal insulating materials, and on a study of the properties of the new synthetic fiber and glass with a view toward their utilization in parachute and wing fabrics.

Some consideration has been given to the finding of a substitute for silk for shroud lines, the development of more satisfactory shock-strut guards and fluids, prerotation of wheels, and safety tires. Work is under way on the development of fillers for small surface depressions such as rivet heads in wings.

The subcommittee is following with interest the work at Langley Field on the development of de-icers, and the cooperative work of the Civil Aeronautics Authority at the National Bureau of Standards on the fire-resistance of aircraft materials. On request, a soap manufacturer is now trying to develop a better soap for cleaning airplanes.

Development of plastic material for aircraft structures.—Eighteen synthetic resins have been tested to determine their suitability for impregnating and bonding wood veneers to form a reinforced plastic of the requisite strength and stability for use in aircraft construction. Nine hot-pressed and three cold-pressed phenol-formaldehyde resins, one phenol-furfural resin, four urea-formaldehyde resins and one vinyl acetal resin were investigated. Great differences were observed in the temperatures and pressures required for obtaining satisfactory bonds with these resins and in their degree of resistance to delaminating when alternately wetted and dried. On the basis of these data three of these resins have been selected for use as bonding and impregnating agents in the preparation of laboratory samples of reinforced plastics for strength tests. These are a phenol-formaldehyde resin which requires hot pressing to obtain a good bond and cure, a phenol-formaldehyde resin which cures at room temperature by catalytic action, and a vinyl acetal resin which is permanently thermoplastic and requires heat to make it flow and effect a bond. These are representative of the resins required for investigating three different methods of molding reinforced plastics, namely (1) use of heat and pressure accompanied by thermal curing of the resin, (2) application of pressure at room temperature accompanied by catalytic curing of the resin, and (3) use of heat and pressure with a permanently fusible resin. The preparation of curved and tubular speci-

mens by methods adaptable to the fabrication of large members is now being investigated.

Tensile and compressive strength, modulus of elasticity, and water absorption have also been determined for a number of plastics which have been proposed by various commercial sources for use in building propellers, floats, spars, wings, and fuselages of airplanes. The reinforcing agents in these products included wood veneer, pressed wood, flax, jute, and sisal. The results obtained indicate that maximum strength and stiffness is attained with well-oriented fibers and thermosetting resins.

Evaluation of new transparent plastics as windshields for aircraft.—The past year has been a period of particularly active development of new transparent plastics, including such materials as cellulose acetropropionate, cellulose acetobutyrate, vinyl chloride-acetate resin, and polystyrene resin. Further improvement in the methyl methacrylate and cellulose acetate plastics has also been effected. An accelerated aging test developed in the course of experimental work on transparent plastics has proved to be a very useful means of rapidly evaluating these new materials with regard to weathering resistance. It is highly desirable that these new and improved materials, which are found to possess the necessary weathering resistance, should be examined with respect to other properties of importance in connection with their use as aircraft windshields and that a specification should be prepared to permit the procurement of transparent plastics which will most satisfactorily meet aircraft requirements.

It is, therefore, proposed to obtain from the respective manufacturers new samples of the transparent plastics which have been found to be outstanding with respect to weathering resistance and to submit them to tests for the following properties: Light transmission, haze, distortion, scratch resistance, impact strength, tensile strength, flexibility, thermal expansion, dimensional stability including both shrinkage and warping, flame resistance, and resistance to action of water, oil, gasoline, grease, and soap solution. The relative resistance of these plastics to weathering will also be established by exposing them in the accelerated aging apparatus for a longer time than the 500 hours which we now use to evaluate outdoor stability. The effect of weathering, both natural and accelerated, on the strength and optical properties of the plastics will be determined. The variation of the strength properties with temperature will be studied over the range from 140° F. to −40° F. A detailed specification will be prepared on the basis of these experimental procedures and results, to cover those materials which are found to be superior for aircraft use.

REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

STRUCTURAL RESEARCH

One of the problems that have confronted designers of stressed-skin and monocoque structures for several years has been the proportioning of intermediate frames and ribs. Heretofore very little consideration has been given to this problem in the literature. During the past year, two investigations of this problem were undertaken. The first was concerned with the loads on intermediate frames and the second was concerned with the stiffness required of these members. In practical design problems, it is desirable to check both the strength and the stiffness of the intermediate frames.

Loads on intermediate frames.—If the flange members of a beam change direction at an intermediate frame, a force is applied to the intermediate frame. This change of direction can either be built in or result from the deflection of the beam.

The practical design formulas for calculating the load on intermediate frames for each of these cases have been summarized in Technical Note No. 687. In this paper, an analysis of diagonal-tension effects in beams with curved webs is also included and a new semiempirical formula for the loads on the stiffeners is proposed.

Stiffness required of ribs.—In the design of stressed-skin wings, it is common practice to assume that the shear webs and ribs are equivalent to rigid supports which divide the stiffened-skin covering into small panels and that the bending strength of the wing depends upon the compressive strength of these panels. This assumption is sound provided the ribs are sufficiently stiff. A first paper on this subject was presented to the Institute of Aeronautical Sciences during the past year. This paper, entitled "On the Rib Stiffness Required for Box Beams," appears in the Journal of the Aeronautical Sciences, May 1939. In this paper the stiffness required of the ribs to divide the compression side of a stressed-skin wing into small panels of length equal to the rib spacing is discussed.

This problem has been further studied and the theory is being extended. This subject is considered one of great importance because, if the ribs of a stressed-skin wing do not have a stiffness equal to or greater than that required to divide the compression surface as assumed, the foundation of the present design procedure crumbles.

Stress distribution in monocoque structures.—The stress distribution in monocoque structures is influenced by several factors, one of the most important of which is the shear deformation of the skin. In most practical

cases, the problem of taking shear deformation into account leads to quite laborious methods of analysis. During the past year, a simple numerical method applicable to these problems, as well as to mathematically related problems, has been developed. This method is completely described in Technical Note No. 704, which also includes a practical example.

Continued efforts are being made to find the simplest possible method of solving increasingly complex problems in stress distribution. A continuous check on the validity of the simplifications is being made by strain-gage tests.

Shell analysis and the shear center.—There has been some confusion as to how established methods of analysis should be applied to shell structures when the loading consists of combined bending and torsion. The basic principles for this analysis have been established for some time. A summary of the practical design formulas has been made and their use illustrated with a number of problems. The summary and problems have been presented in Technical Note No. 691. In this note it is also pointed out that the use of the shear center offers no advantage over the use of any arbitrary reference point.

Method of estimating critical loads.—In most problems of elastic instability the critical buckling load is determined by satisfying certain transcendental equations associated with the condition of neutral stability. In order to solve these equations, it is necessary to assume values of the critical load and to test the equations. By application of methods similar to those proposed by Southwell for the analysis of experimental observations in problems of elastic stability, a method has been developed to estimate quickly the theoretical critical load after the equation for neutral stability has been tested for three assumed critical loads. This method of estimating critical loads, as applied to structural members, has been described in Technical Note No. 717. In this paper a number of examples are given to reveal certain characteristics of the method that should be known by the practical engineer using it.

Local buckling of compression members.—During the past year two papers (Technical Notes Nos. 686 and 722) have been published wherein charts are presented for the coefficient in the formula for critical compressive stress at which cross-sectional distortion begins in columns with rectangular-tube, channel, and Z-sections. This work is being extended to include much more comprehensive treatments for buckling problems in general.

Correlation of structural data.—During the past year, the Committee has received a large amount of structural-test data from the Army Air Corps, the Bureau of Aeronautics of the Navy, the Civil Aeronautics Authority, and the aircraft industry. These data are being studied with a view to correlating as much of it as possible. Steps are being taken to supplement present information with regard to the geometric dimensions of the test specimens, the material properties, and the types of failure.

A valuable result of the study of these data has been to observe what problems have not been attacked by the industry. This information has been used to revise the structural-research programs of the Committee so as to cover important phases of structural design for which information is needed.

STRUCTURAL LOADS ON AIRPLANES

Statistical measurements of gust loads.—Coordinated measurements of acceleration and air speed on transport airplanes have been continued. Although several high accelerations have been recorded during the past year, none of them exceed the maximums previously recorded. This subject is more fully presented under the report of the Subcommittee on Meteorological Problems.

Gust structure.—An investigation of gust structure under a variety of weather conditions and at various altitudes up to 17,000 feet in the vicinity of Langley Field has been concluded. Analysis of the complete data has led to verification of earlier indications that there is no correlation between gust intensity and gust gradient. In the case of gusts encountered in the lower levels of the atmosphere, a fairly high degree of correlation was found to exist between the wind gradient and a gust-intensity index derived from an elementary analysis based on the concept that gusts arising from mechanical friction or disturbances behave in a manner analogous to the behavior of a simple elastic system. In the case of thermal gusts, the maximum intensities measured during surveys of the gust occurring in different weather situations were found to be dependent on the thermal energy available for convection in these situations.

The indications obtained from gust measurements on a number of airplanes of widely different size, considered in conjunction with tests in the gust tunnel, have led to improved working concepts of the relation between maximum gust intensities and corresponding gradients. Although the subject is too involved to discuss here, for practical design purposes there are strong indications that the gradient distance of the gust may be taken as 8.5 chord lengths. Currently used gust factors derived on a somewhat different basis are not in disagreement with this concept and, in fact, have been more firmly established by the more recent data. Recent advances in the theory of unsteady flow likewise do not upset in any way the practical value of the established gust-load criterions.

Gust tunnel.—The results of the first tests in the gust tunnel, reported last year, have been published in Technical Note No. 706.

Tests of a biplane model (Technical Note No. 731) indicate that, when the conventional assumption of the equivalent monoplane is made, calculated accelerations are considerably less than the measured values (20 percent in the case tested). If the wings are assumed to act independently as finite monoplanes, however, agreement between calculated and test results is good, provided the gradient distance does not exceed about 10 to 12 chord lengths. Beyond this distance, a discrepancy appears that is probably due to an increasing approach to steady-flow conditions, with a corresponding increase in induced biplane interference.

Tests on a model of a "canard," or "tail-first," airplane designed to be the equivalent of a particular conventional airplane showed that the "canard" arrangement is unfavorable from considerations of gust loads. In the case studied, the accelerations were about 30 percent higher than those measured on the conventional model throughout the important range of gust gradients.

In order to determine the possibility of reducing gust accelerations by suitable structural design of the wing, a model was provided with a wing flexible in torsion. This wing was tapered, the tip chord being half the root chord, and the construction was such that the tip section twisted $-1.5°$ per load factor with properly distributed load. Comparative tests on the model alternately equipped with the flexible wing and with a rigid wing indicated that the effect of the flexibility was a reduction in acceleration approximately proportional to the gradient distance and having a value of about 16 percent with a gradient distance of 10 chord lengths.

Load distribution.—An analytical study of the variation of the net wing loads under conditions in which combined angular and normal accelerations exist has been completed. This study included the determination of the shear and the moment variation along the wing span during unsymmetrical landings, aileron deflection, and several types of unsymmetrical gusts. The results are being applied in a report, now in preparation, to illustrate the effect of a number of variables such as wing taper, wing weight, and aileron span on the shears and moments.

Tail loads.—The possibility of relating tail loads and load factors in maneuvers has been given considerable attention. Within the past year a set of dynamometer springs has been designed and installed in a small airplane for measuring tail loads. Special apparatus for controlling rate and amount of elevator deflection and other equipment has also been installed.

A brief analysis of the loads on horizontal tail surfaces during recovery from spins indicates that for large modern multiengine airplanes there is considerable danger of failure in this condition. The loads become excessive because of high rates of descent resulting from heavy wing loading, clean design, and steep spinning attitude and because the tail operates at maximum lift coefficient while passing from the stalled state of the spin to the unstalled state following recovery. In one case investigated, the upward-acting tail load during recovery was estimated to be several times the normal design load. Wing loads may also be execessive on large modern airplanes in spins.

Measurements of gust loads on the vertical tail surfaces of a twin-engine airplane have been concluded. The results indicate no simple basis for relating the probable gust loads on tail surfaces to the gust loads on the wings, because the tail loads in rough air are a summation of partial loads caused by the direct action of the gust, the angle of the rudder, the yawing velocity of the airplane, and possibly the position of the surface relative to the slipstream determined by yawing of the airplane and irregularities in the slipstream caused by atmospheric turbulence. In order to study these conditions more fully, as well as to obtain further statistical data, more complete instrumentation has been installed in a modern four-engine airplane.

Loads on seaplane hulls.—Extensive measurements of hull pressures, stresses, and acceleration on two large flying boats have been completed. The results have given a fairly complete qualitative picture of the nature of the loading conditions. They indicate that forward speed plays a predominant part in determining the magnitude of the maximum pressures and that, at a given speed, the maximum pressures may be of the same value at any point on the bottom, the position in any case depending on the attitude of the hull and the conformation of the water surface. These maximum pressures are usually so localized and shift position so rapidly that they are of little direct structural significance, although under some circumstances in rough water the areas involved may be great enough to give rise to high local loads. In regard to the resultant load on the hull, the vertical momentum is of more importance, inasmuch as it determines the depth of immersion and consequently the wetted area over which the mean pressure acts. For example, on a given hull at constant vertical velocity the acceleration was found to increase with beam loading (vertical momentum) because of the increased wetted area.

Dynamic overstress.—Measurements of acceleration and wing stress have been made on a very large airplane in rough air. The results agree with those pre-

viously obtained on an M–130 flying boat in indicating no evidence of dynamic overstress. Measurements of acceleration and wing stress have also been made on a small airplane in maneuvers to demonstrate that the relation between load factor and stress remains the same regardless of the period of application of load under all possible conditions.

NATIONAL BUREAU OF STANDARDS

Tensile and compressive properties of duralumin, magnesium, and alloy steels.—A paper describing the pack method for compressive tests of thin sheet metal has been published during the past year as Technical Report 649.

The pack method was extended to thinner gages and to higher compressive stresses in order to obtain compressive stress-strain curves for 0.02-inch stainless-steel sheet material for the Bureau of Aeronautics, Navy Department. Additional support was obtained by cementing the leaves of the pack together with shellac and by using external clamps of special design. It was possible with this procedure to apply stresses up to 202 kips per square inch to a pack of about 31 leaves of 0.02-inch stainless-steel sheet before failure occurred by sudden instability of the entire pack.

Column tests and crinkling tests were made on closed sections formed from this material by spot-welding with the load along the direction of rolling in the case of half of the specimens and at right angles to the direction of rolling in the case of the other half. The tests showed differences in strength that agreed with the differences expected from the compressive stress-strain graphs.

A number of tests were made to develop a convenient and rapid method for detecting the presence of aeolotropy in compressive properties of thin sheet. The most promising results were obtained by comparing the buckling loads obtained in fixed-end compressive tests of single strips of suitable length cut from the sheet in a transverse and a longitudinal direction. In the case of stainless-steel strips having a length equal to about 20 times their thickness the transverse buckling load exceeded the longitudinal buckling load by about 50 percent.

Beryllium.—Mechanical tests have been made on a number of specimens of beryllium alumium alloy with a beryllium content from 22.6 to 70 percent (nominal). The Young's modulus for these specimens ranged from 14,300 to 30,000 kips per square inch. Tensile tests resulted in a highly curved stress-strain curve in each case, a tensile yield strength (offset, 0.2 percent) ranging from 15.5 to 20.2 kips per square inch, a tensile strength ranging from 22.8 to 29.1 kips per square inch, and an elongation in 1 inch ranging from 2.0 to 9.0 percent.

Flat plates under normal pressure.—The tests of circular plates with clamped edges have been completed and a detailed report has been submitted to the Bureau of Aeronautics, Navy Department. Normal-pressure tests were made on 19 plates 5 inches in diameter ranging in thickness from 0.0149 to 0.0723 inch. Seventeen of the plates consisted of aluminum alloy, one of 18–8 stainless steel and one of magnesium alloy.

The center deflections and stresses at low pressures were found to agree with those calculated for a plate of "medium thickness" from theories by Way and Nadai. At higher pressures the observed center deflections exceeded the calculated values consistently by 4 to 12 percent. With the beginning of permanent set at the center both the total center deflection and the permanent set at the center tended to increase linearly with the pressure for most of the plates.

The pressure required to produce yielding in the plate, as measured by a given permanent set at the center, was between the theoretical pressures for yielding at the edge and for yielding at the center of the plate. Empirical curves are included in the report which relate the pressures for a given permanent set at the center of the plate to the dimensions of the plate and the tensile properties of the material.

Aircraft tubing.—The first portion of the program on high-strength chromium-molybdenum-steel tubing of the type used in landing gears was completed by tests in tension, compression, bending and torsion of tubes whose diameter-thickness ratio ranged fram 12 to 55.

The tests were complicated by the extreme hardness of the material which caused difficulties in seating strain gages and gripping the specimens for test, and by variations in properties in the individual lengths of tubing. However, these difficulties were overcome and enough tests were made so that the strengths are known sufficiently well in terms of the diameter-thickness ratios and the mechanical properties of the material to proceed with tests under combined loading.

Wing beams.—Detailed reports were prepared for the Bureau of Aeronautics, Navy Department, on tests of two series of wing beams under axial loads, transverse loads, and combined axial and transverse loads. The materials were 24ST aluminum alloy in both cases, and the section was an I-section having curved flanges for one series and tilting flanges for the other.

The reports include a stiffness-weight and a strength-weight comparison with the wing beams previously tested for this project (stainless-steel box beams, 17ST and 24ST aluminum-alloy I-beams with straight flanges). For combined axial and transverse loads the strength-weight ratio for all beams tested to date was found to be roughly the same at a slenderness ratio of about 40.

Sheet-stringer panels.—A report of end-compression tests of nine aluminum-alloy sheet-stringer panels was submitted to the Bureau of Aeronautics, Navy Department.

The report gives the results of tests on a series of panels reinforced by three Z-stringers that were fastened to the sheet by brazier-head rivets spaced from 0.5 to 6 inches between centers. Four of the panels failed by separation of rivets at a stringer stress of 24.2 to 39.5 kips per square inch. The remaining panels failed by instability of the stringers at a stringer stress from 38 to 42 kips per square inch.

The observed effective widths of the sheet were from −1 to 20 percent greater than the effective widths calculated from Marguerre's formula for simply supported edges up to an edge strain at which buckling occurred between rivets. The sheet load remained approximately constant after buckling of the sheet between rivets.

Monocoque boxes.—The monocoque box specimen, the elastic deformation of which under axial load and under various types of transverse loading is to be studied, has been tested in compression. The test data have been analyzed and the results have been described in Technical Note No. 721.

Strength of riveted joints in aluminum alloy.—A report on tests of single rivet joints embodying flush rivets has been prepared for the National Advisory Committee for Aeronautics. The report gives the results of static tests in single shear, in double shear, and in tension of 865 joints prepared by seven different aircraft manufacturers, the Naval Aircraft Factory, and the National Bureau of Standards. A series of graphs is included to show directly the relation between the shearing stress, bearing stress, and diameter-thickness (rivet diameter to sheet thickness) ratio for all the single shearing joints tested.

Fatigue testing of aluminum-alloy wing beams.—The third wing beam has been tested to failure in fatigue. The test showed progress toward the solution of certain problems in technique which must be solved whenever structures similar to wing beams are tested by the resonance method under axial loads.

The results for the first two beams tested indicate approximately equal resistance to fatigue throughout the length of each beam, but in the third beam a crack had traversed the web at the edge of the reinforcement near the center of the beam before much more than half the total number of cycles had been completed. This local failure of the web, however, did not lead to final failure of the beam. Cracks later appeared at other points of stress concentration and the final failure was similar to that of the other two beams.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915, and the membership increased from 12 to 15 by act approved March 2, 1929 (U. S. C., title 50, sec. 151). Its membership is appointed by the President and consists of two representatives each of the War and Navy Departments from the offices in charge of military and naval aeronautics, two representatives of the Civil Aeronautics Authority (Civil Aeronautics Act of 1939), one representative each of the Smithsonian Institution, the United States Weather Bureau and the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter six serve for terms of 5 years. All the members serve as such without compensation. During the past year the following changes occurred in the membership of the main Committee:

Dr. Francis W. Reichelderfer, the new Chief of the United States Weather Bureau, was appointed a member on January 2, 1939, to fill the vacancy occasioned by the death on September 14, 1938, of Dr. Willis Ray Gregg, Chief of the United States Weather Bureau.

Brigadier General George H. Brett, United States Army, Chief of Matériel Division, of the Army Air Corps, Dayton, Ohio, was appointed a member of the Committee on March 11, 1939, to succeed Brigadier General Augustine W. Robins, United States Army, relieved because of transfer to other military duty.

Honorable Robert H. Hinckley, Chairman of the Civil Aeronautics Authority, was appointed a member of the Committee, May 20, 1939, to succeed Honorable Edward J. Noble, who had resigned as Chairman of the Civil Aeronautics Authority.

Rear Admiral John H. Towers, United States Navy, was appointed a member on May 20, 1939, effective June 1, 1939, on which date he succeeded Rear Admiral Arthur B. Cook, United States Navy, as Chief of the Bureau of Aeronautics, Admiral Cook having been transferred to sea duty.

Dr. George J. Mead, of West Hartford, Conn., was appointed from civil life a member of the Committee, on October 11, 1939, to fill out the unexpired term of Dr. Joseph S. Ames, who resigned on October 7 because of physical inability to take an active part in the work of the Committee. Dr. Ames had served as a member of the Committee since its establishment in 1915. At the time of his resignation, he was Chairman of the Committee and was serving under a 5-year appointment by President Roosevelt, expiring December 1, 1943. Comment on Dr. Ames' service appears in the opening portion of this report.

Under the rules and regulations governing the work of the Committee, as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee. On October 19th, 1939, Dr. Vannevar Bush, who had served as Vice Chairman of the main Committee and Chairman of the Executive Committee, was elected Chairman of the main Committee to succeed Dr. Ames. Dr. George J. Mead was elected Vice Chairman of the main Committee. Dr. Bush was also elected Chairman of the Executive Committee and Dr. Charles G. Abbot, Vice Chairman of the Executive Committee.

The executive offices of the Committee, including the office of aeronautical intelligence and the office of aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. It serves as the depository and distributing agency for the scientific and technical data on aeronautics comprising the results of fundamental Committee researches and also the scientific and technical information collected by the Committee from governmental and private agencies in this country and abroad. The data collected are classified, catalogued, and disseminated by this office.

The Committee's technical assistant in Europe, Mr. John J. Ide, whose headquarters are at the American Embassy in Paris, visits governmental and private agencies in Europe to collect results of researches and to gain first-hand information as to researches proposed and in progress.

RESEARCH FACILITIES

With the consistent support of the President and of the Congress, the Committee has developed at Langley

Field, Va., a large and well-equipped aeronautical research laboratory, known as the Langley Memorial Aeronautical Laboratory. Advances to date in the relatively new engineering science of aeronautics have been made possible largely by the design and construction at Langley Field of novel research equipment.

At the present time, the Langley Field Laboratory comprises the following units: The 8-foot 500-mile-per-hour wind tunnel; the full-scale wind tunnel with a throat 60 by 30 feet; the 20-foot propeller-research-tunnel; the 5-foot variable-density wind tunnel; a 7- by 10-foot wind tunnel; a 4- by 6-foot vertical wind tunnel; a 15-foot free-spinning wind tunnel; two high-velocity jet-type wind tunnels of 11- and 24-inch throat diameters, respectively; the 2,900-foot N. A. C. A. tank; an engine-research laboratory; a flight-research laboratory; an instrument laboratory; and administration and service buildings. The research facilities at Langley Field also include the following recent additions: A 19-foot pressure wind tunnel; a refrigerated wind tunnel with a throat 7½ by 3 feet; a 12-foot free-flight wind tunnel; and an additional shop building.

The Committee is proceeding to construct at Langley Field a structures research laboratory, a two-dimensional flow wind tunnel, a stability wind tunnel, a 16-foot high-speed wind tunnel and a 20-foot free-spinning wind tunnel.

The Committee has in process of construction at Moffett Field, Calif., a second major research station, authorized by act approved August 9, 1939. The facts in connection with this vitally important addition to the Committee's research facilities follow.

SECOND RESEARCH STATION

At a meeting of the Executive Committee on August 19, 1938, the late Major General Oscar Westover, then Chief of the Army Air Corps, and Chairman of a Special Committee on the Relation of the N. A. C. A. to National Defense in Time of War, recommended that the Committee plan an additional research center somewhere in the interior of the country or on the west coast, in order to relieve the situation he described as "the congested bottle neck of Langley Field." As a result of this suggestion General Westover's committee was requested to make a study of long-range planning for the location of additional laboratory activities for the Committee away from the present laboratory at Langley Field.

During the following month, General Westover and Dr. W. R. Gregg, two of the three members of the special committee, met untimely deaths, leaving Admiral Cook as the sole surviving member. At the meeting of the main Committee on October 20, 1938, a Special Committee on Future Research Facilities was formed consisting of Rear Admiral Arthur B. Cook, chairman, Major General Henry H. Arnold, Honorable Edward J. Noble, Dr. Edward Warner, and Dr. George W. Lewis. This committee studied the need for additional research in aeronautics and the problems involved in a long-range plan for future research facilities as related to national defense and to commercial aviation. The committee also studied the need for more effective coordination of aeronautical research among governmental, industrial, and educational institutions. A subsidiary special committee studied the desirable sites for a second aeronautical research station. As a result of these studies the special committee submitted a report on December 30, 1938, recommending the immediate establishment of a second research station at Sunnyvale, Calif., and the construction of the most advanced research equipment at an estimated cost of $11,000,000. Additional research facilities were recommended for Langley Field, Va., and a plan for the more effective coordination of applied research in industry was outlined as an immediate need.

On February 3, 1939, the President of the United States transmitted to the Congress supplemental estimates amounting to $6,723,000. Of this amount $2,140,000 was for new construction at Langley Field, $36,000 for the proposed coordination plan, $250,000 for contracts for research in scientific and educational institutions, $297,000 for salaries and expenses, and $4,000,000 for construction of facilities at the proposed new Sunnyvale, Calif., research station. Appropriations for salaries and expenses and the new facilities at Langley Field and for the coordination plan were included in the Second Deficiency Act in the total amount of $2,363,980. Authorization of the second research station was included in the Third Deficiency Act approved August 9, 1939. The act carried a total appropriation of $2,000,000. Of this amount $1,890,980 was provided to begin construction of an additional aeronautical research station at a total cost of not to exceed $10,000,000 upon such site as may be chosen by the National Advisory Committee for Aeronautics from the sites brought to its attention within 30 days after approval of the act.

In all, 54 sites for the proposed station were brought to the attention of the Committee within the 30-day period fixed by law and were referred to the Special Survey Committee on Aeronautical Research Facilities, consisting of Colonel Charles A. Lindbergh, chairman, Major General Henry H. Arnold, Rear Admiral John H. Towers, and Honorable Robert H. Hinckley. The characteristics of each of the 54 sites, as described in the proposals and as supplemented by additional inquiries, were subjected to an exhaustive analysis. Some of the factors which were considered in rating the sites for their approach to the ideal included: The nature of the flying field on which the station was pro-

posed, the adequacy and cost of electric power, proximity to a suitable industrial center, proximity to the aircraft industry, climatic conditions especially as related to year-round flying, military vulnerability, adequate transportation facilities, and working and living conditions for employees. The subcommittee recommended and the Committee decided by a unanimous vote, after due consideration, that all things considered the best interests of aeronautics would be served by the location of the second research station at Moffett Field near Sunnyvale, and 38 miles south of San Francisco, Calif. The decision was announced on September 22, 1939.

The new site consists of approximately 100 acres, 60 of which have been assigned to the Committee by the War Department and 40 purchased. Moffett Field is a former naval air station of 1,000 acres originally used for lighter-than-air activities but now under the administration of and actively used by the Army Air Corps. The Committee will conduct its research activities there under a status similar to that under which it functions at Langley Field. The planning and construction of research facilities and equipment are progressing as rapidly as possible. The Committee's present plans do not contemplate the conduct of engine research at the Moffett Field laboratory.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the inventions section received 1,800 inventions and designs pertaining to the aeronautical art. All of these proposals were given careful consideration and evaluated. The necessary correspondence was conducted to advise the submitters of the evaluations and interviews were granted inventors to discuss new proposals and their merits.

AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

The Committee has continued to follow the policy initiated as a result of recommendation of the Federal Aviation Commission, of making available a special allotment of $25,000 from each year's funds for aeronautical research in educational institutions. Under this allotment during the fiscal year 1939, contracts were made for 12 special investigations and reports at 10 universities and technical schools, on the basis of the probable usefulness and value of the information to aeronautics.

Several of the papers prepared under contracts have been published by the Committee, and in other cases the results obtained in the investigations have supplied a basis for further research. During the past year nine contract reports have been issued as Technical Notes and one as a confidential report to American manufacturers, and six others are now being revised and edited for publication by the Committee.

The Committee has given much consideration to this policy and is strongly of the opinion that its activities in the encouragement and stimulation of aeronautical research in educational institutions should be greatly extended, and has recommended in its estimates for 1941 that the funds for the purpose be increased from $25,000 to $250,000. There is a pressing need to marshal the existing scientific resources of the country on a large variety of scientific problems in aeronautics. Furthermore, with the expansion of the air program and intensification of efforts to improve the performance and efficiency of aircraft, and with increased research facilities being made available to the Committee, there will be great need for additional trained research workers in the United States. The training of these workers should be done by educational institutions. Thus this program will accomplish a twofold purpose in supplying new knowledge and in training research workers.

COOPERATION WITH THE AVIATION INDUSTRY

In the formulation of its research programs, the Committee includes provision for the problems of aeronautical research which are of particular importance to the aviation industry, in connection with both the design and operation of aircraft. The representatives of the industry refer their problems of this nature to the Committee as they arise, either by correspondence or through personal contact. The Committee avails itself of every opportunity to obtain suggestions and recommendations from representatives of the aircraft manufacturers and operators as to investigations which are of special importance to them.

For the purpose of familiarizing the industry with the research facilities of the Committee and the programs of research under way, there is held at the Committee's laboratory at Langley Field, Va., once a year, usually in May, an aircraft engineering conference. This conference is attended by the representatives of the aircraft manufacturers and operators. Open dis-

cussions are held wherein suggestions are received which lead to modifications or additions to the programs to obtain the information desired. In some cases these suggestions have initiated new programs of research. It is a long-standing policy of the Committee when the need arises in connection with any particular problem of the industry to call a special conference or to appoint a special subcommittee.

Realizing that frequently the value of information is greatly enhanced by its prompt availability, every effort is made to place in the hands of the industry at the earliest possible date the results of researches that are of particular interest in connection with civil aeronautics. It sometimes appears, in the course of an extensive investigation being conducted by the Committee, that the results so far obtained will be of special interest and value to the aircraft industry if made available immediately. In such cases the Committee issues the information in advance confidential form to American manufacturers and the Government services.

COORDINATION OF AERONAUTICAL RESEARCH

In order to provide for the more effective coordination of applied aeronautical research in industry and to utilize more effectively research facilities at scientific and educational institutions, the Committee has set up, with funds provided by the Congress for the purpose, a new section on coordination. It is the expectation of the Committee that this new activity will have the following beneficial results: It will accelerate progress in aeronautics by bringing the results of research more directly to the attention of designers and engineers in the aircraft industry, and by bringing more promptly to the attention of the Committee new problems requiring scientific study and investigation; it will utilize existing facilities in scientific and educational institutions on a larger scale than in the past, to the extent that additional funds may be made available for the purpose; and it will stimulate scientific research in such institutions, coordinate applied research in industry, and at the same time serve to prevent unnecessary overlapping and duplication of effort.

This is not a new function of the Committee, but is rather an enlargement of an existing function made necessary by the magnitude of the country's air defense program and the need to accelerate progress in the development of American aeronautics, in order that the performance of American aircraft may equal or excel the performance of the aircraft of any other nation. The new section on coordination will operate under the immediate supervision of a coordinator of research, who will be a member of all the standing technical subcommittees and who will have assistants in the field keeping in close touch with the progress and needs of aeronautical science by visiting the aircraft industry and scientific and educational institutions.

SUBCOMMITTEES

The National Advisory Committee for Aeronautics has organized standing technical committees, with subcommittees, for the purpose of coordinating the research needs of aviation and preparing research programs in their respective fields. The four main technical Committees on Aerodynamics, Power Plants for Aircraft, Aircraft Materials, and Aircraft Structures and their subcommittees prepare the programs for the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies.

As previously stated, it is the policy of the Committee to establish from time to time special technical subcommittees for the study of particular problems as they arise, and several such special subcommittees have been organized.

The work of the standing technical committees and subcommittees has been described in part I. Their organization, together with that of the special technical subcommittees, is as follows:

COMMITTEE ON AERODYNAMICS

Dr. Edward Warner, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Dr. L. J. Briggs, National Bureau of Standards.
Maj. F. O. Carroll, Air Corps, United States Army, Matériel Division, Wright Field.
Comdr. W. S. Diehl, United States Navy.
Dr. H. L. Dryden, National Bureau of Standards.
John Easton, Civil Aeronautics Authority.
Mr. J. T. Gray, Civil Aeronautics Authority.
Maj. Carl F. Greene, Air Corps, United States Army, Matériel Division Liaison Officer at N. A. C. A. Laboratories.
Delbert M. Little, United States Weather Bureau.
Maj. Alfred J. Lyon, Air Corps, United States Army, Matériel Division.
Elton W. Miller, National Advisory Committee for Aeronautics.
Comdr. F. W. Pennoyer, Jr., United States Navy.
H. J. E. Reid, National Advisory Committee for Aeronautics.
Comdr. Leslie C. Stevens, United States Navy.
Mr. Omer Welling, Civil Aeronautics Authority.
Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

SUBCOMMITTEE ON AIRSHIPS

Dr. J. C. Hunsaker, Chairman.
Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.
John Easton, Civil Aeronautics Authority.
Captain Garland Fulton, United States Navy.
Maj. C. F. Greene, Air Corps, United States Army, Matériel Division Liaison Officer at N. A. C. A. Laboratories.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Dr. F. W. Reichelderfer, United States Weather Bureau, Chairman.
Col. E. S. Gorrell, Air Transport Association of America.
Dr. W. J. Humphreys, United States Weather Bureau.
Dr. J. C. Hunsaker, Massachusetts Institute of Technology.
R. W. Knight, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Delbert M. Little, United States Weather Bureau.
Comdr. Wilber M. Lockhart, United States Navy.
Capt. R. M. Losey, Air Corps, United States Army.
Dr. Charles F. Marvin.
Mr. Richard V. Rhode, National Advisory Committee for Aeronautics.
Dr. C. G. Rossby, United States Weather Bureau.

SPECIAL SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

Delbert M. Little, United States Weather Bureau, Chairman.
J. C. Franklin, Transcontinental & Western Air, Inc.
Dr. O. H. Gish, Carnegie Institution of Washington.
Commander L. M. Grant, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
K. B. McEachron, General Electric Company.
Irving R. Metcalf, Civil Aeronautics Authority.
Capt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. F. B. Silsbee, National Bureau of Standards.

SUBCOMMITTEE ON SEAPLANES

Dr. J. C. Hunsaker, Chairman.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Commander W. S. Diehl, United States Navy.
J. T. Gray, Civil Aerouautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Capt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
A. L. Morse, Civil Aeronautics Authority.
Capt. H. C. Richardson, United States Navy.
Starr Truscott, National Advisory Committee for Aeronautics.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

H. J. E. Reid, National Advisory Committee for Aeronautics, Chairman.
Capt. Frederick R. Dent, Jr., Air Corps, United States Army, Matériel Division, Wright Field.
Comdr. W. S. Diehl, United States Navy.
Comdr. L. M. Grant, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Comdr. R. D. MacCart, United States Navy.
Irving R. Metcalf, Civil Aeronautics Authority.
Ford Prescott, Matériel Division, Army Air Corps, Wright Field.
Dr. Walter Ramberg, National Bureau of Standards.
Edward I. Ryder, Civil Aeronautics Authority.
Benjamin Smilg, Matériel Division, Army Air Corps, Wright Field.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Dr. George J. Mead, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Comdr. Rico Botta, United States Navy.
Dr. H. C. Dickinson, National Bureau of Standards.
John H. Geisse, Civil Aeronautics Authority.
Carlton Kemper, National Advisory Committee for Aeronautics.
Gaylord W. Newton, Civil Aeronautics Authority.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Chairman.
Commander Rico Botta, United States Navy.
Dr. O. C. Bridgeman, National Bureau of Standards.
H. K. Cummings, National Bureau of Standards.
Dr. H. C. Dickinson, National Bureau of Standards.
Lt. Henry R. Dozier, United States Navy.
L. S. Hobbs, The Pratt and Whitney Aircraft Company.
Robert V. Kerley, Matériel Division, Army Air Corps, Wright Field.
Gaylord W. Newton, Civil Aeronautics Authority.
Arthur Nutt, Wright Aeronautical Corporation.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.
Addison M. Rothrock, National Advisory Committee for Aeronautics.

COMMITTEE ON AIRCRAFT MATERIALS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.
S. K. Colby, Aluminum Co. of America.
Lt. Comdr. C. F. Cotton, United States Navy.
Edgar H. Dix, Jr., American Magnesium Corporation.
John Easton, Civil Aeronautics Authority.
Warren E. Emley, National Bureau of Standards.
Capt. Garland Fulton, United States Navy.
J. T. Gray, Civil Aeronautics Authority.
C. H. Helms, National Advisory Committee for Aeronautics.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
H. S. Rawdon, National Bureau of Standards.
John W. Sands, International Nickel Company.
E. C. Smith, Republic Steel Corporation.
Paul F. Voigt, Jr., Carnegie-Illinois Steel Corporation.
Dr. Edward Warner.

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

H. S. Rawdon, National Bureau of Standards, Chairman.
A. W. Dallas, Civil Aeronautics Authority.
E. H. Dix, Jr., American Magnesium Corporation.
Capt. Garland Fulton, United States Navy.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
E. C. Smith, Republic Steel Corporation.
Prof. H. L. Whittemore, National Bureau of Standards.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

Warren E. Emley, National Bureau of Standards, Chairman.
C. J. Cleary, Matériel Division, Army Air Corps, Wright Field.
A. W. Dallas, Civil Aeronautics Authority.
C. H. Helms, National Advisory Committee for Aeronautics.
E. F. Hickson, National Bureau of Standards.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
J. E. Sullivan, Bureau of Aeronautics, Navy Department.
G. W. Trayer, Forest Service, Department of Agriculture.

COMMITTEE ON AIRCRAFT STRUCTURES

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
John Easton, Civil Aeronautics Authority.
Comdr. L. M. Grant, United States Navy.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Comdr. R. D. MacCart, United States Navy.
Capt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. Walter Ramberg, National Bureau of Standards.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. L. B. Tuckerman, National Bureau of Standards.
Dr. Edward Warner.

SPECIAL SUBCOMMITTEE TO MAKE SURVEY OF TECHNIQUE AND EQUIPMENT FOR ELASTIC EXAMINATION OF LARGE AIRCRAFT STRUCTURES IN LIEU OF DESTRUCTION TESTS

Richard V. Rhode, National Advisory Committee for Aeronautics, Chairman.
Comdr. L. M. Grant, United States Navy.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Comdr. R. D. MacCart, United States Navy.
Irving R. Metcalf, Civil Aeronautics Authority.
R. L. Templin, Aluminum Company of America.
Dr. L. B. Tuckerman, National Bureau of Standards.

SPECIAL SUBCOMMITTEE TO DIRECT RESEARCH IN APPLIED STRUCTURES

Comdr. L. M. Grant, United States Navy, Chairman.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. L. B. Tuckerman, National Bureau of Standards.

COMMITTEE ON AIRCRAFT ACCIDENTS

Dr. Edward Warner, Chairman.
Thomas Hardin, Air Safety Board, Vice Chairman.
Lt. Comdr. W. A. Evans, Jr., United States Navy.
Maj. Barney M. Giles, Air Corps, United States Army.
J. W. Lankford, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics.
Comdr. A. E. Montgomery, United States Navy.
Maj. Lowell H. Smith, Air Corps, United States Army.
Grove Webster, Civil Aeronautics Authority.

COMMITTEE ON AERONAUTICAL INVENTIONS AND DESIGNS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
Brig. Gen. George H. Brett, Air Corps, United States Army, Matériel Division, Wright Field.
Hon. Clinton M. Hester, Civil Aeronautics Authority.
Dr. J. C. Hunsaker.
Capt. S. M. Kraus, United States Navy.
John F. Victory, Secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Vannevar Bush, Chairman.
Dr. Charles G. Abbot.
Dr. George J. Mead.
John F. Victory, Secretary.

During the past year the Committee has organized the following special committees for the study of particular problems:

SPECIAL SURVEY COMMITTEE ON AERONAUTICAL RESEARCH FACILITIES

Col. Charles A. Lindbergh, Chairman.
Maj. Gen. Henry H. Arnold, Chief of the Air Corps, United States Army, War Department.
Rear Admiral J. H. Towers, Chief, Bureau of Aeronautics, United States Navy, Navy Department.
Hon. Robert H. Hinckley, Chairman, Civil Aeronautics Authority.

SPECIAL COMMITTEE ON COORDINATION

Dr. Jerome C. Hunsaker, Massachusetts Institute of Technology, Chairman.
Capt. Sydney M. Kraus, United States Navy.
Brig. Gen. George H. Brett, United States Army, Chief of the Matériel Division, Air Corps.
Dr. George W. Lewis, Director of Aeronautical Research, National Advisory Committee for Aeronautics.
Dr. Edward Warner, Civil Aeronautics Authority.

SPECIAL COMMITTEE ON NEW ENGINE RESEARCH FACILITIES

Dr. George J. Mead, Chairman.
Comdr. Rico Botta, United States Navy.
R. M. Hazen, Allison Engineering Division, General Motors Corporation.
S. D. Heron, Ethyl Gasoline Corporation.
L. S. Hobbs, Pratt and Whitney Aircraft Company.

Carlton Kemper, National Advisory Committee for Aeronautics.

Gaylord W. Newton, Civil Aeronautics Authority.

Arthur Nutt, Wright Aeronautical Corporation.

Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detailed problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft. No aircraft circulars were issued during the past year.

The following are lists of the publications issued:

LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

645. Correction of Temperatures of Air-Cooled Engine Cylinders for Variation in Engine and Cooling Conditions. By Oscar W. Schey, Benjamin Pinkel, and Herman H. Ellerbrock, Jr., N. A. C. A.

646. The Compressibility Burble and the Effect of Compressibility on Pressures and Forces Acting on an Airfoil. By John Stack, W. F. Lindsey, and Robert E. Littell, N. A. C. A.

647. Tests of N. A. C. A. 0009, 0012, and 0018 Airfoils in the Full-Scale Tunnel. By Harry J. Goett and W. Kenneth Bullivant, N. A. C. A.

648. Design Charts for Predicting Downwash Angles and Wake Characteristics behind Plain and Flapped Wings. By Abe Silverstein and S. Katzoff, N. A. C. A.

649. The "Pack" Method for Compressive Tests of Thin Specimens of Materials Used in Thin-Wall Structures. By C. S. Aitchison and L. B. Tuckerman, National Bureau of Standards.

650. The Aerodynamic Characteristics of Six Full-Scale Propellers Having Different Airfoil Sections. By David Biermann and Edwin P. Hartman, N. A. C. A.

651. Downwash and Wake behind Plain and Flapped Airfoils. By Abe Silverstein, S. Katzoff, and W. Kenneth Bullivant, N. A. C. A.

652. Air Flow in the Boundary Layer of an Elliptic Cylinder. By G. B. Schubauer, National Bureau of Standards.

653. A Study of Air Flow in an Engine Cylinder. By Dana W. Lee, N. A. C. A.

654. General Airplane Performance. By W. C. Rockefeller, California Institute of Technology.

655. The Knocking Characteristics of Fuels in Relation to Maximum Permissible Performance of Aircraft Engines. By A. M. Rothrock and Arnold E. Biermann, N. A. C. A.

656. The Column Strength of Two Extruded Aluminum-Alloy H-Sections. By William R. Osgood and Marshall Holt, National Bureau of Standards and Aluminum Company of America.

657. The Influence of Directed Air Flow on Combustion in a Spark-Ignition Engine. By A. M. Rothrock and R. C. Spencer, N. A. C. A.

658. Tests of Two Full-Scale Propellers with Different Pitch Distributions, at Blade Angles up to 60°. By David Biermann and Edwin P. Hartman, N. A. C. A.

659. Effect of Service Stresses on Impact Resistance, X-ray Diffraction Patterns, and Microstructure of 25S Aluminum Alloy. By J. A. Kies and G. W. Quick, National Bureau of Standards.

660. Experimental Investigation of the Momentum Method for Determining Profile Drag. By Harry J. Goett, N. A. C. A.

661. Tests in the Variable-Density Wind Tunnel of the N. A. C. A. 23012 Airfoil with Plain and Split Flaps. By Ira H. Abbott and Harry Greenberg, N. A. C. A.

662. Design of N. A. C. A. Cowlings for Radial Air-Cooled Engines. By George W. Stickle, N. A. C. A.

663. The Effect of Continuous Weathering on Light Metal Alloys Used in Aircraft. By Willard Mutchler, National Bureau of Standards

664. Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil with Various Arrangements of Slotted Flaps. By Carl J. Wenzinger and Thomas A. Harris, N. A. C. A.

665. Calculation of the Aerodynamic Characteristics of Tapered Wings with Partial-Span Flaps. By Henry A. Pearson and Raymond F. Anderson, N. A. C. A.

666. Aircraft Rate-of-Climb Indicators. By Daniel P. Johnson, National Bureau of Standards.

667. Determination of the Profile Drag of an Airplane Wing in Flight at High Reynolds Numbers. By Joseph Bicknel, N. A. C. A.

668. Wind-Tunnel Investigation of N. A. C. A. 23012, 23021, and 23030 Airfoils with Various Sizes of Split Flap. By Carl J. Wenzinger and Thomas A. Harris, N. A. C. A.

669. Airfoil Section Data Obtained in the N. A. C. A. Variable-Density Tunnel as Affected by Support Interference and Other Corrections. By Eastman N. Jacobs and Ira H. Abbott, N. A. C. A.

670. Tensile Elastic Properties of 18:8 Chromium-Nickel Steel as Affected by Plastic Deformation. By D. J. McAdam, Jr., and R. W. Mebs, National Bureau of Standards.

671. A Theoretical Study of the Moment on a Body in a Compressible Fluid. By Carl Kaplan, N. A. C. A.

672. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. IV. Effect of Center-of-Gravity Location. By Oscar Seidman and A. I. Neihouse, N. A. C. A.

673. Experimental Verification of the Theory of Oscillating Airfoils. By Abe Silverstein and Upshur T. Joyner, N. A. C. A.

674. Cooling on the Front of an Air-Cooled Engine Cylinder in a Conventional Engine Cowling. By M. J. Brevoort and U. T. Joyner, N. A. C. A.

675. Effects of Elevator Nose Shape, Gap, Balance and Tabs on the Aerodynamic Characteristics of a Horizontal Tail Surface. By Harry J. Goett and J. P. Reeder, N. A. C. A.

676. Surface Heat-Transfer Coefficients of Finned Cylinders. By Herman H. Ellerbrock, Jr., and Arnold Biermann, N. A. C. A.

677. Wind-Tunnel Investigation of an N. A. C. A. 23021 Airfoil with Various Arrangements of Slotted Flaps. By Carl J. Wenzinger and Thomas A. Harris, N. A. C. A.

678. Interference of Tail Surfaces and Wing and Fuselage from Tests of 17 Combinations in the N. A. C. A. Variable-Density Tunnel. By Albert Sherman, N. A. C. A.

679. Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil with a Slotted Flap and Three Types of Auxiliary Flap By Carl J. Wenzinger and William E. Gauvain, N. A. C. A.

680. The Effect of Nacelle-Propeller Diameter Ratio on Body Interference and on Propeller and Cooling Characteristics. By James G. McHugh and Eldridge H. Derring, N. A. C. A.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

667. Operational Treatment of the Nonuniform-Lift Theory in Airplane Dynamics. By Robert T. Jones, N. A. C. A.

668. Hydrodynamic and Aerodynamic Tests of Models of Flying-Boat Hulls Designed for Low Aerodynamic Drag—N. A. C. A. Models 74, 74–A, and 75. By Starr Truscott, J. B. Parkinson, John W. Ebert, Jr., and E. Floyd Valentine, N. A. C. A.

669. The Drag of Inflatable Rubber De-icers. By Russell G. Robinson, N. A. C. A.

670. N. A. C. A. Stall-Warning Indicator. By F. L. Thompson, N. A. C. A.

671. A Method of Rapidly Estimating the Position of the Laminar Separation Point. By Albert E. von Doenhoff, N. A. C. A.

672. Flow Observations with Tufts and Lampblack of the Stalling of Four Typical Airfoil Sections in the N. A. C. A. Variable-Density Tunnel. By Ira H. Abbott and Albert Sherman, N. A. C. A.

673. The Pressure Available for Ground Cooling in Front of the Cowling of Air-Cooled Airplane Engines. By George W. Stickle and Upshur T. Joyner, N. A. C. A.

674. Scavenging a Piston-Ported Two-Stroke Cylinder. By A. R. Rogowski and C. L. Bouchard, Massachusetts Institute of Technology.

675. The Charging Process in a High-Speed, Single-Cylinder, Four-Stroke Engine. By Blake Reynolds, Harry Shecter, and E. S. Taylor, Massachusetts Institute of Technology.

676. Discharge Characteristics of a Simulated Unit Injection System. By Edred T. Marsh, N. A. C. A.

677. Tests of a Contra-Propeller for Aircraft. By William M. Benson, Daniel Guggenheim Aeronautical Laboratory, Stanford University.

678. Hydrodynamic and Aerodynamic Tests of Four Models of Outboard Floats (N. A. C. A. Models 51–A, 51–B, 51–C, 51–D). By John R. Dawson and Edwin P. Hartman, N. A. C. A.

679. Noise from Propellers with Symmetrical Sections at Zero Blade Angle, II. By A. F. Deming, N. A. C. A.

680. The Aerodynamic Drag of Five Models of Side Floats, N. A. C. A. Models 51–E, 51–F, 51–G, 51–H, and 51–J. By R. O. House, N. A. C. A.

681. A General Tank Test of a Model of the Hull of the P3M–1 Flying Boat Including a Special Working Chart for the Determination of Hull Performance. By John R. Dawson, N. A. C. A.

682. The Unsteady Lift of a Finite Wing. By Robert T. Jones, N. A. C. A.

683. Pressure-Distribution Measurements on a Tapered Wing with a Full-Span Split Flap in Curved Flight. By Th. Troller and F. Rokus, Daniel Guggenheim Airship Institute, Akron, Ohio.

684. Experimental Study of Deformation and of Effective Width in Axially Loaded Sheet-Stringer Panels. By Walter Ramberg, Albert E. McPherson, and Sam Levy, National Bureau of Standards.

685. Circulation Measurements about the Tip of an Airfoil During Flight through a Gust. By Arnold M. Kuethe, Daniel Guggenheim Airship Institute, Akron, Ohio.

686. Local Instability of Symmetrical Rectangular Tubes Under Axial Compression. By Eugene E. Lundquist, N. A. C. A.

687. Loads Imposed on Intermediate Frames of Stiffened Shells. By Paul Kuhn, N. A. C. A.

688. Comparative Performance of Engines Using a Carburetor, Manifold Injection, and Cylinder Injection. By Oscar W. Schey and J. Denny Clark, N. A. C. A.

689. Tandem Air Propellers. By E. P. Lesley, Daniel Guggenheim Aeronautical Laboratory, Stanford University.

690. Résumé of Air-Load Data on Slats and Flaps. By Carl J. Wenzinger and Francis M. Rogallo, N. A. C. A.

691. Some Elementary Principles of Shell Stress Analysis with Notes on the Use of the Shear Center. By Paul Kuhn, N. A. C. A.

692. Some Fundamental Considerations in Regard to the Use of Power in Landing an Airplane. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.

693. Comparison of Profile-Drag and Boundary-Layer Measurements Obtained in Flight and in the Full-Scale Wind Tunnel. By Harry J. Goett and Joseph Bicknell, N. A. C. A.

694. Physical Properties of Synthetic Resin Materials. By Meyer Fishbein, N. A. C. A.

695. The Effects of Some Common Surface Irregularities on Wing Drag. By Manley J. Hood, N. A. C. A.

696. Torsional Stability of Aluminum Alloy Seamless Tubing. By R. L. Moore and D. A. Paul, Aluminum Research Laboratories, Aluminum Company of America.

697. The Frequency of Torsional Vibration of a Tapered Beam. By Robert P. Coleman, N. A. C. A.

698. Propeller Tests to Determine the Effect of Number of Blades at Two Typical Solidities. By E. P. Lesley, Daniel Guggenheim Aeronautical Laboratory, Stanford University.

699. Tests of an N. A. C. A. 23012 Airfoil with a Slotted Deflector Flap. By R. O. House, N. A. C. A.

700. Theory of Automatic Control of Airplanes. By Herbert K. Weiss, Massachusetts Institute of Technology.

701. Intermittent-Flow Coefficients of a Poppet Valve. By C. D. Waldron, N. A. C. A.

702. Wind-Tunnel Tests of Several Forms of Fixed Wing Slot in Combination with a Slotted Flap on an N. A. C. A. 23012 Airfoil. By M. J. Bamber, N. A. C. A.

703. Wind-Tunnel Investigation of Effect of Yaw on Lateral-Stability Characteristics. I—Four N. A. C. A. 23012 Wings of Various Plan Forms with and without Dihedral. By M. J. Bamber and R. O. House, N. A. C. A.

704. Some Notes on the Numerical Solution of Shear-Lag and Mathematically Related Problems. By Paul Kuhn, N. A. C. A.

705. Wind-Tunnel Investigation of Ground Effect on Wings with Flaps. By Isidore G. Recant.

706. An Experimental Investigation of the Normal Acceleration of an Airplane Model in a Gust. By Philip Donely, N. A. C. A.
707. Compression-Ignition Engine Performance with Undoped and Doped Fuel Oils and Alcohol Mixtures. By Charles S. Moore and Hampton H. Foster, N. A. C. A.
708. A Simplified Method for the Calculation of Airfoil Pressure Distribution. By H. Julien Allen, N. A. C. A.
709. A Semigraphical Method for Analyzing Strains Measured on Three or Four Gage Lines Intersecting at 45°. By H. N. Hill, Aluminum Research Laboratories, Aluminum Company of America.
710. A Comparison of Ignition Characteristics of Diesel Fuels as Determined in Engines and in a Constant-Volume Bomb. By Robert F. Selden, N. A. C. A.
711. An Approximate Spin Design Criterion for Monoplanes. By Oscar Seidman and Charles J. Donlan, N. A. C. A.
712. A Preliminary Study of the Prevention of Ice on Aircraft by the Use of Engine-Exhaust Heat. By Lewis A. Rodert, N. A. C. A.
713. A Comparison of Several Tapered Wings Designed to Avoid Tip Stalling. By Raymond F. Anderson, N. A. C. A.
714. Flight Tests of Retractable Ailerons on a Highly Tapered Wing. By J. W. Wetmore, N. A. C. A.
715. Wind-Tunnel Investigation of an N. A. C. A. 23012 Airfoil with Two Arrangements of a Wide-Chord Slotted Flap By Thomas A. Harris, N. A. C. A.
716. Hydrodynamic and Aerodynamic Tests of a Family of Models of Seaplane Floats with Varying Angles of Dead Rise N. A. C. A. Models 57–A, 57–B, and 57–C. By John B. Parkinson, Roland E. Olson, and Rufus O. House, N. A. C. A.
717. A Method of Estimating the Critical Buckling Load for Structural Members. By Eugene E. Lundquist, N. A. C. A.
718. Resistance of Transparent Plastics to Impact. By Benjamin M. Axilrod and Gordon M. Kline, National Bureau of Standards.
719. The Effects of Partial-Span Slotted Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered N. A. C. A. 23012 Wing. By Rufus O. House, N. A. C. A.
720. Flight Tests of N. A. C. A. Nose-Slot Cowlings on the BFC–1 Airplane. By George W. Stickle, N. A. C. A.
721. Compressive Tests of a Monocoque Box. By Walter Ramberg, Albert E. McPherson, and Sam Levy, National Bureau of Standards.
722. Local Instability of Centrally Loaded Columns of Channel Section and Z-Section. By Eugene E. Lundquist, N. A. C. A.
723. Adhesion of Ice in Its Relation to the De-icing of Airplanes. By A. M. Rothrock and R. F. Selden, N. A. C. A.
724. The Effects of Surface Waviness and of Rib Stitching on Wing Drag. By Manley J. Hood, N. A. C. A.
725. Tank Tests to Determine the Effects of the Chine Flare of a Flying-Boat Hull N. A. C. A. Model Series 62 and 69. By Joe W. Bell and Roland E. Olson, N. A. C. A.
726. Combined Beam-Column Stresses of Aluminum-Alloy Channel Sections. By R. Gottlieb, T. M. Thompson, and E. C. Witt, University of Maryland.
727. A Flight Investigation of the Distribution of Ice-Inhibiting Fluids on a Propeller Blade. By Lewis A. Rodert, N. A. C. A.
728. Wind-Tunnel Investigation of an N. A. C. A. 23021 Airfoil with Two Arrangements of a 40-Percent-Chord Slotted Flap. By Frank Duschik, N. A. C. A.
729. An Instrument for Estimating Tautness of Doped Fabrics on Aircraft. By Gordon M. Kline and Herbert F. Schiefer, National Bureau of Standards.
730. Wind-Tunnel Investigation of Effect of Yaw on Lateral-Stability Characteristics. II—Rectangular N. A. C. A. 23012 Wing with a Circular Fuselage and a Fin. By M. J. Bamber and R. O. House, N. A. C. A.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

878. The Twisting of Thin-Walled Stiffened Circular Cylinders. By E. Schapitz. From Lilienthal-Gesellschaft für Luftfahrtforschung Jahrbuch, 1936.
879. Static Longitudinal Stability and Longitudinal Control of Autogiro Rotors. By M. Schrenk. From Luftfahrtforschung, June 6, 1938.
880. The Effective Width of Curved Sheet after Buckling. By W. A. Wenzek. From Luftfahrtforschung, July 6, 1938.
881. Application and Testing of Transparent Plastics Used in Airplane Construction. By K. Riechers and J. Olms. From Luftwissen, June 1938.
882. Modern Manufacturing Equipment of the Ernst Heinkel Airplane Works. By A. Thormann and H. Jockisch. From Luftfahrtforschung, January 20, 1938.
883. Distribution of Temperatures over an Airplane Wing with Reference to the Phenomena of Ice Formation. By Edmond Brun. From Publications Scientifiques et Techniques du Ministere de l'Air, No. 119, 1938.
884. Calculation of the Induced Efficiency of Heavily Loaded Propellers Having Infinite Number of Blades. By F. Lösch.
The Induced Efficiency of Optimum Propellers Having a Finite Number of Blades. By K. N. Kramer.
Prospects of Propeller Drive for High Flying Speeds. By G. Bock and R. Nikodemus.
From Luftfahrtforschung, July 6, 1938.
885. Meteorological-Physical Limitations of Icing in the Atmosphere. By W. Findeisen. From Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12–15, 1938.
886. Theory of Two-Dimensional Potential Flow about Arbitrary Wing Sections. By H. Gebelein. From Ingenieur-Archiv, June 1938.
887. Comparison of Theory with Experiment in the Phenomenon of Wing Flutter. By P. Cicala. From L'Aerotecnica, April 1938.
888. Ice Formation on Wings. By L. Ritz. From Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12–15, 1938.
889. Investigation of the Lift Distribution Over the Separate Wings of a Biplane. By D. Küchemann. From Luftfahrtforschung, October 10, 1938.
890. Experiments on a Slotted Wing. By P. Ruden. From Deutsche Luftfahrtforschung Jahrbuch, 1937.
891. Theoretical and Experimental Study of Ignition Lag and Engine Knock. By Fritz A. F. Schmidt. From VDI—Forschungsheft 392—Supplement to Forschung auf dem Gebiete des Ingenieurwesens, September–October, 1938.
892. Investigations and Tests in the Towing Basin at Guidonia. By C. Cremona. From Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12–15, 1938.

893. Contribution to the Theory of the Heated Duct Radiator. By H. Winter. From Luftfahrtforschung, October 10, 1938.
894. The Way to Increased Airplane Engine Power. By Eugen Vohrer. From Luftwissen, October 1938.
895. The Power of Aircraft Engines at Altitude. By Paolo Ragazzi. From Hauptversammlung der Lilienthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12–15, 1938.
896. The Drag of Airplane Radiators with Special Reference to Air Heating (Comparison of Theory and Experiment). By B. Göthert. From Luftfahrtforschung, September 10, 1938.
897. Airfoil Theory at Supersonic Speed. By H. Schlichting. From Deutsche Luftfahrtforschung Jahrbuch, 1937.
898. The Limit of Stability of a Curved Plate Strip Under Shear and Axial Stresses. By A. Kromm. From Luftfahrtforschung, October 10, 1938.
899. The Hydrodynamic Theory of Detonation. By Heinz Langweiler. From Zeitschrift für Technische Physik, Vol. 19, No. 9, 1938.
900. The Effect of the Masses of the Controls on the Longitudinal Stability with Free Elevator. By Rudolf Schmidt. Part I. From Luftfahrtforschung, January 10, 1939.
901. Investigations and Experiments in the Guidonia Supersonic Wind Tunnel. By Antonio Ferri. From Hauptversammlunr der Lilienthal-Gesellschaft für Luftfahrtforschung, Berlin, October 12–15, 1938.
902. Design of Centrifugal Impeller Blades. By A. Betz and I. Flügge-Lotz. From Ingenieur-Archiv, December 1938.
903. Effect of Transition in Cross-Sectional Shape on the Development of the Velocity and Pressure Distribution of Turbulent Flow in Pipes. By Erwin Mayer. From VDI-Forschungsheft 389—Supplement to Forschung auf dem Gebiete des Ingenieurwesens, March/April 1938.
904. Stability of Rectangular Plates with Longitudinal or Transverse Stiffeners Under Uniform Compression. By R. Barbre. From Ingenieur-Archiv, Vol. VIII, No. 2, 1937.
905. Temperature-Indicating Paints. By F. Penzig. From Zeitschrift des Vereines deutscher Ingenieure, January 21, 1939.
906. Forces and Moments on a Yawed Airfoil. By Sighard Hoerner. From Luftfahrtforschung, April 20, 1939.
907. Dynamic Stability of a Helicopter with Hinged Rotor Blades. By K. Hohenemser. From Ingenieur-Archiv, December 1938.
908. Two-Stroke-Cycle Engines with Unsymmetrical Control Diagram (Supercharged Engines). By J. Zeman. From Automobiltechnische Zeitschrift, August 25, 1938.
909. The Theory of Contra-Vanes Applied to the Propeller. By Albert Betz. From Ingenieur-Archiv, December 1938.
910. Measurements on a Low-Wing Model in the Rotating Jet and Comparison with Flight Measurements. By W. Bader. From Luftfahrtforschung, February 20, 1939.
911. Knocking in the Otto-Cycle Engine. By H. Weinhart. From Luftfahrtforschung, February 20, 1939.

FINANCIAL REPORT

Appropriations and expenditures, 1939.—The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1939, as contained in the Independent Offices Appropriation Act approved May 23, 1938, was $1,679,000. A supplemental appropriation of $223,980 was made available in the Second Deficiency Appropriation Act, fiscal year 1939, approved May 2, 1939, for the same purposes specified in the Committee's regular appropriation act for 1939, to continue available until June 30, 1940. The total amount available for general purposes during the fiscal year 1939, therefore, was $1,902,980. The amount expended and obligated under the regular appropriation was $1,678,996 and under the supplemental appropriation $29,434, making a total of $1,708,430, itemized as follows:

Personal services	$1,065,812
Supplies and materials	85,146
Communication service	3,722
Travel expenses	15,135
Transportation of things	2,479
Furnishing of electricity	43,518
Repairs and alterations	5,820
Special and miscellaneous investigations	69,384
Contracts for research	24,968
Equipment	192,446
Structures	200,000
Expended and obligated	1,708,430
Unexpended balance	4
Balance of supplemental appropriation, available for expenditure during fiscal year 1940	194,546
Total, general appropriation	1,902,980

The appropriation for printing and binding for 1939 was $21,000, of which $20,996 was expended.

The Second Deficiency Appropriation Act also provided $2,140,000 for the construction and equipment of additional facilities at Langley Field, Va., including connections to public utilities, and rights-of-way for, and installation of power lines, this amount to remain available until expended. No obligations were placed under this fund during the fiscal year 1939.

The amount of $6,500 was received during the fiscal year 1939 and credited to three special deposit accounts to cover the cost of scientific investigations for manufacturers. Also one remittance of $1,130 was carried over on account of an uncompleted investigation started in 1938. These four investigations were completed during 1939, resulting in the deposit of $6,345.52 to Miscellaneous Receipts in the Treasury, as proceeds, and the return of unexpended balances totaling $1,284.48 to depositors.

An allotment of $400 was received from the State Department for payments during the fiscal year 1939 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies. Of this amount $71 was paid during the fiscal year 1939 to employees of the Committee stationed in the Paris office, leaving a balance of $329 which was turned back into the Treasury.

An allotment of $1,000 was made to the Committee for preparation of models for exhibit at the Golden Gate International Exposition at San Francisco. The total amount was expended for that purpose.

Appropriations for fiscal year 1940.—The general appropriation for the fiscal year 1940, as contained in the Independent Offices Appropriation Act approved March 16, 1939, was $1,717,000, and the amount provided for printing and binding was $23,000. This act also provided $340,000 for the completion of the two-dimensional wind tunnel for which the 1939 act had provided an initial amount of $200,000, and $100,000 which will be used for the modernization of the free spinning wind tunnel. The total amount provided under the Independent Offices Act for 1940, therefore was $2,180,000.

The Second Deficiency Appropriation Act, fiscal year 1939, approved May 2, 1939, provided $2,140,000 for the construction and equipment of additional facilities at Langley Field, Va., including connections to public utilities, and rights-of-way for, and installation of power lines, this amount to remain available until expended. Also provided under the Second Deficiency Act for general purposes for the fiscal years 1939 and 1940 was an additional sum of $223,980, of which there was at the end of the fiscal year 1939 a balance of $194,546 available for obligation in the fiscal year 1940, thus making the total amount available under this act for expenditure in 1940, $2,334,546.

The Third Deficiency Appropriation Act, fiscal year 1939, approved August 9, 1939, provided $1,890,980 for beginning construction of an additional research laboratory and authorized the Committee to enter into contracts for construction and equipment, including the purchase of land, not to exceed a total of $10,000,000. Also included in this act was an item of $109,020 for additional personnel, making the total amount of $2,000,000 available under this act for expenditure during 1940.

The total amount available for expenditure during 1940 under the three acts mentioned is $6,514,546.

Estimates for fiscal year 1941.—The Committee's estimates for the fiscal year 1941 include the amount of $3,899,513 for general purposes and $30,000 for printing and binding. The amount of $1,177,475 is requested for additional facilities at Langley Field, and $5,699,020 for construction of new facilities at Moffett Field. The total amount of the regular estimates for 1941 is $10,806,008.

CONCLUSION

The Committee is grateful to the President and to the Congress for the liberal support of its work in the past and especially for the recent approval of a second major research station to be located at Moffett Field, Calif. It strongly urges approval of its recommendations for the construction of a special engine research laboratory and for the stimulation and support of research in scientific and educational institutions.

In the present disturbed condition of world affairs, the importance of accelerating aeronautical progress in the United States cannot be overemphasized. The Committee has been careful and practical in presenting its needs and urges that the appropriations recommended be approved. Nothing will have a more fundamental influence on the progress of American aeronautics than liberal support of a well-rounded and comprehensive program for scientific research. The Army, the Navy, and the Civil Aeronautics Authority depend upon the National Advisory Committee for Aeronautics to meet the research needs of aviation and to provide the constant stream of new knowledge necessary to keep the United States in the forefront of progressive nations in the development of aeronautics for both military and commercial purposes.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS,
VANNEVAR BUSH, *Chairman.*

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Twenty-sixth Annual Report

of the

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ADMINISTRATIVE REPORT
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TWENTY-SIXTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1940

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

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LETTER OF TRANSMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Twenty-sixth Annual Report of the Committee covering the fiscal year ended June 30, 1940.

Franklin D. Roosevelt.

The White House,
January 13, 1941.

LETTER OF SUBMITTAL

National Advisory Committee for Aeronautics,
Navy Building, Washington, D. C.,
December 27, 1940.

Mr. President:

In compliance with the provisions of the Act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to submit herewith the Twenty-Sixth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1940.

As results of the Committee's investigations are in an increasing measure of a secret or confidential character, this annual report, out of consideration for the public interest, does not disclose the full scope of the Committee's work.

One of the essential requisites for retaining leadership in the technical development of aircraft is more and more research. Technical progress is so rapid and the advantages of new improvements so great that research in time of emergency is of even greater relative importance than in time of peace.

The Committee has organized its research activities to answer primarily the research needs of the military services, including special and direct collaboration with aircraft manufacturers on matters looking to improvement in the design and performance of American aircraft.

With increased research facilities at Langley Field and at Moffett Field, California, there is a definite acceleration of progress in improving aircraft performance. Recent authorization of an aircraft engine research laboratory, which will be constructed at Cleveland, Ohio, will further strengthen the Committee in its efforts to keep the United States foremost in the technical development of aircraft.

Respectfully submitted.

Vannevar Bush, *Chairman.*

The President,
The White House, Washington, D. C.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

VANNEVAR BUSH, Sc. D., *Chairman*,
Washington, D. C.
GEORGE J. MEAD, Sc. D., *Vice Chairman*,
Washington, D. C.
CHARLES G. ABBOT, Sc. D.,
Secretary, Smithsonian Institution.
HENRY H. ARNOLD, Major General, United States Army,
Deputy Chief of Staff, Chief of the Air Corps, War Department.
GEORGE H. BRETT, Major General, United States Army,
Acting Chief of the Air Corps, War Department.
LYMAN J. BRIGGS, Ph. D.,
Director, National Bureau of Standards.
DONALD H. CONNOLLY, B. S.,
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Bureau of Aeronautics, Navy Department.
FRANCIS W. REICHELDERFER, Sc. D.,
Chief, United States Weather Bureau.
JOHN H. TOWERS, Rear Admiral, United States Navy,
Chief, Bureau of Aeronautics, Navy Department.
EDWARD WARNER, Sc. D.,
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ORVILLE WRIGHT, Sc. D.,
Dayton, Ohio.

GEORGE W. LEWIS, *Director of Aeronautical Research*

S. PAUL JOHNSTON, *Coordinator of Research*

JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer-in-Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

SMITH J. DEFRANCE, *Engineer-in-Charge, Ames Aeronautical Laboratory, Moffett Field, Calif.*

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS

AIRCRAFT STRUCTURES
AIRCRAFT ACCIDENTS
INVENTIONS AND DESIGNS

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Meeting, April 18, 1940

Left to right, seated: Dr. F. W. Reichelderfer, Chief, United States Weather Bureau; Clinton M. Hester, Administrator, Civil Aeronauties Authority; Robert H. Hinckley, Assistant Secretary of Commerce; Rear Admiral John H. Towers, Chief, Bureau of Aeronautics, Navy Department; Major General Henry H. Arnold, Deputy Chief of Staff, Chief of the Air Corps, War Department; Dr. Orville Wright; Dr. Robert E. Doherty; Dr. Vannevar Bush, Chairman; Dr. George J. Mead, Vice Chairman; Dr. Charles G. Abbot, Secretary, Smithsonian Institution; Dr. Edward Warner; Dr. L. J. Briggs, Director, National Bureau of Standards; Major General George H. Brett, Acting Chief of the Air Corps, War Department; Captain Sydney M. Kraus, Bureau of Aeronauties, Navy Department; Dr. Jerome C. Hunsaker. Standing: S. Paul Johnston, Coordinator of Research; Dr. George W. Lewis, Director of Aeronautical Researeh; John F. Victory, Secretary.

TWENTY-SIXTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 26, 1940.*

TO THE CONGRESS OF THE UNITED STATES:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151), which established the National Advisory Committee for Aeronautics, the Committee submits herewith its Twenty-sixth Annual Report for the fiscal year 1940.

The Committee has found it necessary in the national interests to withhold from public distribution the detailed results of its researches. Therefore, until world conditions change, this and succeeding Annual Reports will deal only in general terms with the results accomplished.

This report describes in general terms many investigations now in progress, each of which may be expected to add something in speed, maneuverability, load capacity, range, safety, or economy, to the merit of American airplanes. Several of these investigations already definitely promise large advances. The Committee has been called upon to investigate problems of immediate importance to the Army and Navy involving the means of obtaining the quickest and greatest possible improvements in the performance of aircraft. The Committee's function therein is limited to questions of aeronautics. Designing adapted to meet military requirements lies in the province of the military services.

The most significant developments of the past year in relation to the Committee's work may be briefly summarized as follows:

1. A rapid trend for the improvement of aircraft performance growing out of the war in Europe and reflected in the demands upon the Committee by the Army and Navy for basic new data essential for the design of aircraft of ever-increasing performance.

2. Great expansion in aircraft production requiring the development of quantity production methods.

3. An extensive Army and Navy experimental program for the production of new types of aircraft to meet constantly increasing performance requirements.

4. The authorization by law of an aircraft engine-research laboratory which will be a third major research station for the Committee.

The trend in aircraft development.—The outstanding trend produced by the present war in Europe is toward the development of aircraft having higher speeds and greatly increased armor and armament.

To meet the requirements of increased air speed, special research studies have been made of airplanes in current production and also of experimental types. These studies have included investigations in the full-scale wind tunnel in the Committee's Langley Field laboratory and also the study of the drag of component parts.

The demand for increased speed has resulted in the need for much greater horsepower. Whereas pursuit airplanes of a year ago were equipped with engines of 1,000 horsepower, they are now being designed with single engines of 2,000 horsepower. The trends toward increased speed and higher ceiling, toward larger and heavier engines, toward increased armor and armament, necessitate larger and much heavier types of airplanes. This condition has established a definite trend toward higher wing loadings.

Because of the higher flying speeds demanded by the Army and Navy, the Committee has given special study to the important subject of compressibility shock encountered at high speeds. With the speeds now attainable, it is essential that care be taken to design all parts of the airplane structure so as to prevent velocities approaching the speed of sound from occurring at any point. The 500-mile-per-hour wind tunnel at the Committee's Langley Field laboratory has proved of great value in the study of this problem.

With increased wing loading, it has become necessary to extend the study of improved high-lift devices and of lateral-control devices other than ailerons so as to permit the development of a full-span flap. The trend toward higher speeds has brought many attendant problems, such as the need for improved methods of cowling and cooling of engines, the design of wing ducts, and of ducts for the cooling of engine auxiliaries. High operating speeds also make it necessary to give special attention to the design of air scoops and ventilators.

Relation of research to aircraft production program.—Of more immediate interest to the Army, the Navy, and the Council of National Defense is: What can the Committee's research organization do to improve the performance of the aircraft that are to be procured under the current aircraft production program? The Committee's Langley Field laboratory is engaged in criti-

cal studies of many types of aircraft proposed for production, using either air-cooled or liquid-cooled engines. The Committee is rendering every possible assistance to the Army and Navy to increase to the limit attainable the speeds of airplanes going into production, so that they will be of maximum value for military use.

Relation of research to new types of aircraft.—The national defense demands that improved types of airplanes should be developed as rapidly as possible, since other nations are continually making improvements, and we must not fall behind. Basic research, therefore, cannot be discontinued, no matter how pressing may be the design problems of the moment. It is essential that research laboratories produce a constant flow of new knowledge that will permit the design of airplanes of ever-increasing performance to meet the requirements of the Army and Navy. The Army and Navy have maintained the closest contact with the Committee's laboratories and have taken the fullest advantage of the Committee's facilities in the solution of their pressing problems. The Army Air Corps has appointed at the Committee's laboratory at Langley Field a liaison officer, and the Navy's liaison officer, having headquarters in Washington, visits Langley Field at regular and frequent intervals.

Expansion of research facilities.—The Committee has two major research laboratories, one at Langley Field, Va., known as the Langley Memorial Aeronautical Laboratory, and the other at Moffett Field, Calif., known as the Ames Aeronautical Laboratory. The latter was authorized by act of Congress approved August 9, 1939. The flight research laboratory was the first unit of the Ames Laboratory to get into operation. Other units will be placed in operation as rapidly as their construction is completed.

Both the Langley Memorial Aeronautical Laboratory and the Ames Aeronautical Laboratory are devoted chiefly to aerodynamics, although the Committee has at Langley Field a structures research laboratory, a hydrodynamics research laboratory and a small engine research laboratory. To remedy the deficiency in engine research facilities the Congress by act approved June 26, 1940, authorized the construction of a third major research station for the Committee which is to be an aircraft engine research laboratory. The site finally selected by the Committee under authority of that act is adjoining the municipal airport at Cleveland, Ohio, and the Committee is proceeding with its construction. The details of this action are set forth in Part II of this report.

The Committee highly appreciates the support of the President and the Congress in providing these two additional research stations during the past 2 years. They were indispensable to strengthen research and to accelerate aeronautical progress in the United States. They will prove of great value to the national defense, and it is confidently predicted that their economic value to the Nation will more than offset their cost.

Responsibilities of the Committee.—Under the law it is the duty of the National Advisory Committee for Aeronautics to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution" and also to "direct and conduct research and experiment in aeronautics."

To assist in the discharge of these duties and in the determination of present and future research needs of aeronautics, civil and military, the Committee has established standing technical subcommittees on aerodynamics, power plants for aircraft, aircraft materials, and aircraft structures. The subcommittees are composed of specially qualified representatives of the governmental agencies concerned and of experts from private life. The members of the subcommittees, like the members of the main Committee, serve as such without compensation.

The subcommittees prepare and recommend research programs. Most of the problems recommended for investigation are assigned to the Committee's laboratories. Some problems are assigned to the National Bureau of Standards, when it is to the advantage of the Government to do so in order effectively to utilize existing governmental facilities. Problems are also assigned to universities and technical schools. This policy, the Committee believes, makes effective use of university research facilities, stimulates and coordinates aeronautical research, and also has the advantage of training research personnel.

The Committee regards it as its duty to forecast the trend of aeronautical development, civil and military; to anticipate the research problems that will arise; to design and provide research equipment as needed to solve the problems; to conduct the more fundamental scientific investigations in its own laboratories; and to transmit the results directly to the governmental agencies and to those units of the aircraft industry that are most concerned.

Relation of research to commercial air transportation and to private flying.—The United States has an outstanding place in commercial and private aviation. The current civilian pilot training program of the Civil Aeronautics Administration will, without doubt, serve further to stimulate private flying in the United States and to give it an impetus which will have far-reaching results in the years to come. The progress in civil and commercial aviation in the United States has been due to a combination of causes. The responsible Government agencies have provided indispensable assistance in

the encouragement and regulation of civil and commercial aviation. The American aircraft industry has been keenly alert to improve the design and quality of the aircraft used. The air transport lines have shown initiative and efficiency in operation and have been thorough in their efforts to eliminate accidents and the causes of accidents. The results of the Committee's scientific researches, even though now initiated for the most part to meet military needs, are generally applicable to civil aircraft and are in no small measure responsible for their high efficiency and safety.

In the present emergency when the needs of national defense are predominant, ways and means should nevertheless be found to sustain and continue the advance of commercial aeronautics. Air mail and passenger transportation have already become of great value to the Nation and in time of war would be essential to our industrial effectiveness.

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PART I

REPORTS OF TECHNICAL COMMITTEES

In order to carry out effectively its functions of supervision, conduct, and coordination of research, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields. As a result of the nature of their organization, which includes representation from various governmental agencies concerned with aeronautics, together with experts from civil life, the technical committees act as coordinating agencies, providing effectively for the interchange of information and ideas and for the prevention of duplication.

In addition to its standing committees and subcommittees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The Committee has four principal technical committees—the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, the Committee on Aircraft Materials, and the Committee on Aircraft Structures. Under these committees there are nine standing subcommittees and six special technical subcommittees. The membership of these groups is listed in Part II.

The Committees on Aerodynamics and Power Plants for Aircraft recommend the programs for, and keep in touch with research in these two major fields conducted at the Committee's laboratories and the special investigations conducted at educational institutions and at the National Bureau of Standards. Most of the research under the cognizance of the Committee on Aircraft Materials and a large part of the research under the cognizance of the Committee on Aircraft Structures are conducted at the National Bureau of Standards. In addition, a number of structural investigations, including in particular investigations of a theoretical nature, are conducted at the Committee's laboratory at Langley Field and at educational institutions.

The four technical committees recommend to the main Committee the investigations in their respective fields to be undertaken by educational and scientific institutions under contract with the National Advisory Committee for Aeronautics, and keep in touch with the progress of the work and the results obtained. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and aircraft structures undertaken by the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and other Government agencies are reported to these four committees.

REPORT OF COMMITTEE ON AERODYNAMICS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANDING SPEED AND SPEED RANGE

Continual increase in the wing loadings of modern high-performance airplanes has necessitated continued research directed toward the development of more efficient high-lift devices. The Committee, as in the past several years, has devoted considerable effort to the investigation of the more promising types of trailing-edge flaps.

The investigation of wings with slotted flaps in the 7- by 10-foot wind tunnel has been continued. The results of the tests of the 30-percent thick airfoil with slotted flaps, mentioned in last year's report, have now been published in Technical Note No. 755.

The NACA 23012 and 23021 airfoils have been tested with two sizes of split flaps of airfoil section that were arranged to move backward as well as downward. These flaps were tested over a large range of positions and deflections, both with and without a gap or a slot between the nose of the flap and the airfoil.

Tests have also been made of a small-chord model with a Gwinn and a plain flap. These results are reported in Technical Note No. 763.

CONTROL AND CONTROLLABILITY

The Committee's flight investigation of the flying qualities of various airplanes, which has been actively continued during the past year, has resulted in the accumulation of a considerable fund of data on the control characteristics of present-day airplanes ranging in size from the smallest training airplane to the largest transports and bombers. It has been possible through analysis of these data to specify satisfactory lateral control in the form of an easily measured criterion. Analysis of the data has also shown the influence of various design features on the observed air-

plane characteristics and has yielded a method by which aileron effectiveness can be quickly predicted from a knowledge of airplane dimensions.

As a preliminary step in evaluating the requirements of the elevator control, an analysis is being made of the use of elevators in landing, the principal limiting design condition for the elevator control. Recorded data obtained in a great number of actual landings of airplanes of various types are being correlated with data obtained under comparable conditions at altitude.

The investigation in the 7- by 10-foot wind tunnel of lateral-control devices has been continued. The data on spoiler, deflector, and slot devices have been analyzed.

STABILITY

The flight investigation of the flying qualities of numerous airplanes has contributed a considerable fund of information on the stability characteristics of existing modern airplanes. During the past year, analyses of these data, particularly those relating to longitudinal stability, have been made with two objectives in mind. One objective was to determine the degree of correlation that could be obtained between quantitative values measured during flight tests and the pilot's impression of the suitability of the airplane for the performance of the normal functions of the machine. It was found that the measured characteristics could be correlated with the pilot's impression when the control movement and the corresponding control force required to maneuver the airplane were taken as a criterion of the practical stability. On this basis, satisfactory and unsatisfactory airplanes were properly rated in terms of their measured characteristics. Another consideration was the determination of the effect of various design features on the observed stability characteristics. In this connection it is noteworthy that the fuselage and the engine nacelle moments were among the principal destabilizing agents. Predictions of stability that ignore these factors are greatly in error, but it is possible by semiempirical means to take into account the destabilizing effect of these bodies for the prediction of power-off longitudinal stability.

As a result of independent tests of many airplanes in the full-scale wind tunnel, a large amount of data has been accumulated relating to the effects of the propeller slipstream on the longitudinal stability and control of airplanes. These data are being reviewed and correlated to show some of the more important consistent effects of the slipstream.

To determine the influence of the different airplane parts on the over-all characteristics of the airplane, a study has been completed showing the effects of dihedral and fin area on aileron and rudder control. Of particular interest is the relatively large effect of the vertical-fin area on the aileron effectiveness and operating force.

The investigation of the aerodynamic characteristics of tail surfaces is being continued by the measurements of section characteristics in the 4- by 6-foot wind tunnel. The first phase of the work, pressure-distribution tests of an NACA 0009 airfoil with three sizes of unbalanced movable surfaces, each with three sizes of tabs, has been completed. These data are presented in Technical Notes Nos. 734, 759, and 761. From a further analysis of the results, charts of the principal design parameters have been prepared to enable the designer to determine the aerodynamic characteristics of any unbalanced movable surface. The agreement between the experimentally determined and the theoretical values of the parameters is good except for the prediction of hinge-moment coefficients for narrow-chord flaps. The analysis also indicates that the largest stick forces should be expected with flap-airfoil chord ratios from 0.40 to 0.60. The effect of gap between the unbalanced flap and the fixed surface has been investigated. The tests to determine the effects of flap nose shape and aerodynamic balance with and without gaps are being continued.

Research on the influence of the design variables on lateral-stability characteristics has been continued in the 7- by 10-foot wind tunnel. Large changes in tail effectiveness with changes in the vertical position of the wing on the fuselage have been noted. The vertical-tail effectiveness was decreased when the wing was in a high position on the fuselage and was increased when the wing was in a low position. Flap deflection increased the tail effectiveness regardless of wing position.

This lateral-stability investigation is being extended to include the effects of fore-and-aft position of the wing on the fuselage.

During the year, investigation in the 7- by 10-foot wind tunnel of the power-on stability characteristics of models of present-day airplanes was begun. A technique for reproducing in this tunnel the thrust of the full-scale airplane over the entire flight range has been developed, and complete tests of a model of a low-wing pursuit-type airplane have been made.

In stability studies, as in gust research, the growth of lift on the wing following a sudden change of conditions is of extreme importance and has been the subject of some study. The work on this subject is presented in Technical Report No. 681. A further study has been made dealing with the effect of a sudden change of angle of attack on the lift of the horizontal tail, taking into account the variation in the downwash angle at the flow over the wing.

The study of lateral stability, as affected by the automatic pilot, has been completed.

During the past year the new 12-foot free-flight wind tunnel has been used for the investigation of the stability and the control of five airplane designs.

The models are flown both without power and when powered by small electric motors.

SPINNING

The 15-foot free-spinning wind tunnel has been used in the investigation of spinning characteristics of new airplane designs. In all, 23 models were tested. The greatest emphasis was placed on the determination of the general characteristics of the spins of large multiengine airplanes.

The analysis of the data from the spin tests of a low-wing monoplane with various wing and tail arrangements is now practically complete. The test work has been extended to cover the case of a high-wing monoplane. In general, it appears that the high-wing position has a very favorable effect on the recovery characteristics as compared with the low-wing position.

Flight and wind-tunnel spin tests of a low-wing monoplane have been completed and the agreement shown, although good, is not completely satisfactory.

STALLING

A part of the investigation of flying qualities previously mentioned consisted of observations of the stalling characteristics of each airplane tested in flight. These studies of stalling have provided important information on practical design considerations affecting the stall and have, in particular, emphasized the interrelation of the stability of the airplane at low speeds with the apparent character of the actual stall. At the request of the Civil Aeronautics Authority, particular attention during the past year has been devoted to a study of means for improving the stalling characteristics of several very light airplanes. These airplanes are used almost exclusively by private owners or for preliminary flight training. The investigations have been directed toward developing flying characteristics that would prevent the complete stall from developing regardless of the manipulation of the controls or the power condition, and at the same time to retain adequate control by the pilot for any normal aerial or ground maneuver. The possibility of spinning could thus be averted. In a series of tests with one representative light airplane it was found that, by slight modifications mainly to the wing and the tail surfaces, lateral instability due to stalling could be prevented for all conditions of power; at the same time, a normal amount of control for all essential functions could be retained. It should be noted that, if spinning is desired for instruction purposes, it would be possible to arrange the controls so that a quick change in the control linkage would make stalling possible. Further experiments are under way in an effort to extend these characteristics through a greater center-of-gravity range.

The analysis of the effect of taper, twist, change of camber, and Reynolds number on the stalling characteristics of wings without flaps, mentioned in last year's report, was completed during the year. The analysis is now being extended to include the case of flaps of various deflections and span lengths.

MANEUVERABILITY

The characteristics of various airplanes in accelerated maneuvers have been studied in connection with the general investigations of flying qualities. Data obtained have shown the desirable limits for longitudinal stability as well as stick forces. In this connection, a marked variation of the stability required with wing loading was observed.

LANDING

The investigation of the landing characteristics of airplanes to obtain statistical information on the vertical velocities and accelerations in landings has been extended to include tests of several small, light airplanes. The investigation has now covered practically the entire range of landplane types and sizes, including several airplanes with tricycle landing gears.

The results of a theoretical study of the shimmy of castering wheels first mentioned in the 1938 report have been published as Technical Report No. 686. The report on the investigation of the friction required to prevent shimmy for various arrangements of the swiveling wheel has been published as Technical Note No. 760. These results indicate that the theory, as covered in the above-mentioned report, is adequate for calculating the necessary damping. The effects of type of tire and pressure of the tire were found to be insignificant. The solid friction required to prevent shimmy increased with increased moment of inertia of the spindle and with increased caster angle.

In accordance with a request from the Civil Aeronautics Authority, the Committee investigated the landing distance of a typical transport airplane to aid in clarifying the problem of field size required for such machines in civil transport operation.

AERODYNAMIC EFFICIENCY

Tests of military airplanes in the Committee's full-scale tunnel over the past several years have demonstrated the extreme importance of aerodynamic refinement as applied to even the smallest details. The gains due to the refinement of any one detail may not be large, but the over-all effect of applying the results of basic research to each detail in turn may, when taken together, produce surprising results. Such results as have already been accomplished are strikingly brought out by a comparison of modern military airplanes with those employed during the last war.

Airfoils.—Basic investigations of the aerodynamic properties of airfoils have led to marked advances in our fundamental knowledge of aerodynamic flows in

general. The wing section affords an ideal medium on which to investigate the general properties of aerodynamic flows.

The significance of wind-tunnel turbulence in bringing about a break-down of the low-drag laminar flow on airfoil surfaces has been appreciated for many years. Therefore, every effort was made to reduce the turbulence in the new airfoil-testing equipment to a condition that may be referred to as "aerodynamically smooth" flow, that is, a turbulence level below which further reductions in turbulence would produce no further effects of practical importance. As mentioned in last year's report, preliminary tests with the new equipment indicated that the turbulence level had been reduced below that of other wind tunnels. The airfoil studies were therefore continued, pending the completion of more careful flight investigations made specifically for purposes of comparison. One of the improved airfoils arising from the investigation has now been tested in several of the Committee's wind tunnels to gain further knowledge of the practical effects of the turbulence present in the air streams of existing wind tunnels. Through the cooperation of the National Bureau of Standards, it has been possible to examine the absolute turbulence of the same air streams through the use of hot-wire equipment.

In the full-scale tunnel, data had previously been secured for a series of conventional symmetrical airfoils ranging from 9 to 18 percent in thickness (Technical Report No. 647). During the past year, this investigation has been extended to include airfoils of 25 and 35 percent thickness. Otherwise, airfoil testing of the usual type has been almost discontinued.

Aerodynamic interference.—Investigations dealing with nacelle and propeller interference mentioned in earlier reports have continued during the year. Interferences between wings and propellers have been further investigated in both the propeller-research tunnel and the full-scale tunnel.

In the full-scale tunnel, interference investigations have been extended to include various nacelle arrangements for both two- and four-engine airplanes. The relative size of the nacelles was sufficiently varied to simulate the conditions encountered for a range of large airplanes, varying in size from 6½ to 100 tons. With the completion of this work, the remaining problems appear to be more dependent upon detailed arrangements of the power plant installation than on the general interference effects produced.

Propeller research.—Force tests were conducted on three full-scale propellers operating in front of four body-nose shapes, varying from a streamline nose that continued through the propeller plane in the form of a large spinner to a conventional open-nose radial-engine cowling.

An analysis of the propeller losses in the slipstream has been made by the use of the distribution of the thrust and the torque along the radius combined with theoretical equations. The data were obtained in the NACA 20-foot tunnel on a two-blade propeller of 4-foot diameter. A method was derived for estimating the axial and the rotational energy in the wake as a fractional part of the propeller power for any propeller under any operating conditions.

Propeller development.—The development of propeller-blade sections mentioned in last year's report is being continued in the 24-inch high-speed tunnel. The investigation has yielded new propeller-blade sections that may be expected to permit important gains in propeller efficiency, particularly for high-speed military types where the compressibility effect on the propeller is beginning to appear as the most serious obstacle to great gains in high-speed performance. Even in commercial applications, however, some gains may be expected to result from the use of improved blade sections.

Cowling and cooling.—Some of the most important technical problems on which the Committee has been engaged during the past year were concerned with cowling and cooling of aircraft engines. Investigations have dealt not only with the installation and the cooling of both liquid- and air-cooled engines but also with the character and the efficiency of the flow in the various auxiliary internal-flow systems associated with the modern airplane. Extensive work during the year, dealing mainly with military applications and conducted in nearly all of the Committee's wind tunnels, is yielding new information concerning the details of the engine installation and the effects of the cooling and the auxiliary internal-flow systems on the external flow and the over-all characteristics of the airplane.

The program dealing primarily with the flow in the internal ducts is being carried out in the propeller-research tunnel. This investigation deals with such problems as blowers, ducts, diffusers, and vanes, with the object of studying the possible improvements in the efficiency of the internal systems. The question of securing adequate ground cooling has also received further attention.

COMPRESSIBILITY EFFECTS

The method of successive approximations, attributed to Janzen and Rayleigh, has been used to calculate the flow of a compressible fluid past a sphere to the third order of approximation. The results of this investigation have been presented in Technical Note No. 762.

Further investigation has been continued on the effect of compressibility on the moment of an arbitrary body. This study has been instituted mainly for the purpose of obtaining some insight into the underlying

assumptions and the range of applicability of the Prandtl-Glauert approximation.

Much basic work on compressibility effects has been done following the fundamental investigations of the compressibility problem in the small high-speed tunnels. Further investigations have been made, however, of the conditions under which the compressibility burble occurs. The phenomenon was first observed in the 11-inch high-speed tunnel as it occurred on a circular cylinder. Subsequently a series of cylinders was tested in this tunnel. The drags, when plotted against Reynolds number, showed substantial agreement with the earlier classic investigations in the low-speed range well below four-tenths the speed of sound. A small and progressive increase in drag coefficient was observed for each of the cylinders when approaching this speed; and each of the cylinders showed a much more abrupt increase beyond this speed, where the compressibility burble was observed to occur. Owing to the small size of the tunnel, it was not possible to carry these investigations through the range of critical Reynolds number for the cylinders. It has been possible through the use of the 8-foot high-speed tunnel to extend the investigation to include cylinders of several inches in diameter and extending through the critical range of Reynolds numbers. The results are now being analyzed to study the flow phenomenon associated with the combined critical effects of both Reynolds number and compressibility.

The new 19-foot pressure tunnel, which has been put into operation during the past year has provided an excellent means of separating certain effects of Reynolds number and compressibility, although it was not designed for high speeds and the investigation of compressibility effects. By a variation of the pressure in the tunnel, it is possible with the same model to reach the same Reynolds number at various speeds or Mach numbers, depending on the pressure or the density of the air in the tunnel.

WIND-TUNNEL CORRECTIONS

Corrections for tunnel-wall interference have required further study during the year, owing to the use of relatively large models for extending the test range of Reynolds number. Such studies have resulted in more accurate determinations of tunnel-restriction effects associated with the use of large models. The tunnel-restriction effects are more serious in the high-speed range, owing to the stream distortions associated with compressibility.

ICE FORMATION

Aerodynamic theory has been applied to some of the problems associated with the icing of airplane wings. One phase of the subject investigated dealt with the relative space cleared of water droplets by the passage of the wing. This subject is of importance under conditions corresponding to those of the most severe icing.

The results of the investigation of ice prevention on windshields mentioned last year have been published as Technical Note No. 754. The double-pane windshield with hot air circulating between the two glass panes, which appeared to be the most promising method investigated, was found to increase the reflection of stray light, and in one case this increase was reported to be an obstacle to its use in night landings. Possible means of overcoming this difficulty are under investigation.

The investigation of the use of exhaust heat for ice prevention on airplane wings has been continued. Various methods of distributing the heat available in the engine exhaust have been studied by tests of a wing model mounted on an airplane in flight. The results of this investigation have provided useful data on the most effective means for distributing the available heat.

ROTATING-WING AIRCRAFT

The investigations of the stalling of inboard elements of the retreating rotor blade on the YG–1B autogiro have been reported in Technical Note No. 741. Similar investigations of the same machine equipped with rotor blades of improved design have been completed during the past year. The results indicate that the size and the importance of that portion of an autogiro rotor disk where blade elements operate beyond their stalling angle are appreciably influenced by the static stalling angle of the airfoil section chosen for the rotor blade. They also show that the elimination of control-stick vibration in direct-control rotating-wing aircraft requires the use of rotor blades that do not twist periodically during rotation. Much work has been done on the extension of existing rotor theory.

NATIONAL BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Wind-tunnel turbulence.—With the development by the Committee of new airfoils of extremely low drag the question of wind-tunnel turbulence assumes even greater importance than before. Accordingly, much attention has been given to practicable methods of reducing the turbulence in existing wind tunnels.

In cooperation with the Langley Field staff, measurements were made of the longitudinal and transverse components of turbulence in a number of wind tunnels and in flight by means of portable hot-wire equipment. The flight results, in agreement with previous measurements by other methods at the Committee's

laboratory, indicated that the small-scale turbulence of the atmosphere is substantially zero and hence that wind tunnels should have as low a turbulence as possible.

Boundary-layer investigations.—The study of transition at low turbulence levels on a thin, flat plate parallel to the wind direction has been continued. The effects of small pressure gradients near zero pressure gradient have been determined. The change in position of the transition region with turbulence has been measured over the range from 0.04 to 0.27 percent turbulence (mean of the three components).

Greater attention has been given, however, to the detailed study of the transition region under conditions of the lowest turbulence in the effort to obtain a more fundamental understanding of the process. Measurements and photographic records have been obtained of the longitudinal and transverse components of the turbulent fluctuations parallel to the plate.

A few records have been made of the simultaneous fluctuations at two points. Similar measurements and records have been taken in the laminar layer to study the "pulsations" discovered in earlier work.

Hot-wire equipment.—There has been a steady development of improved equipment for use in turbulence measurement. Amplifiers of greater sensitivity and stability and of less weight, hot-wire holders and supports of greater ruggedness and adapted to special purposes have led to quicker and more accurate measurements. A thorough study was made of the effects of variation of the heating current produced by the changing resistance of the wire during turbulent speed fluctuations. The two-wire head for measurement of transverse components, and its convenient control circuits, are now standard equipment.

The principal developments have been in connection with suitable mountings for making measurements within boundary layers that are free from spurious results due to vibration.

AERONAUTIC-INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

The report on the first phase of the investigation of corrugated diaphragms was published as Technical Note No. 738. Experimental work continued actively during the year on determining the useful deflection limits of the beryllium copper and phosphor bronze diaphragms in which the drift, elastic hysteresis, and after-effect are used as criteria. A method of suddenly applying and removing pressure on the diaphragms was developed in connection with the drift measurements.

At the suggestion of the Langley Memorial Aeronautical Laboratory additional data at higher piston speeds were obtained for inclusion in the report on dashpots. This work extended the data into the turbulent region where the damping resistance increases considerably above that predicted by the theory based on viscous flow.

A standard barometer of the U-tube type has been constructed for standardizing mercurial barometers used to test altimeters. It is equipped with means for controlling and measuring the vacuum above the mercury column and is temperature-controlled. The precision of reading attained at present is 0.02 millimeter of mercury.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The Subcommittee on Meteorological Problems keeps in contact with the progress of investigations being conducted by the various agencies on problems relating to atmospheric conditions which are of particular importance in connection with aircraft design and operation. The Special Subcommittee on Lightning Hazards to Aircraft is organized under the Subcommittee on Meteorological Problems.

Atmospheric disturbances and their effect on airplane operation.—The total flight time with V–G recorders installed in transport airplanes has been increased to more than 103,000 hours. Of this total, approximately 60,000 flight hours have been on land transports flying the airlines in the United States; the rest of the flight hours have been on the flying boats of Pan American Airways, Inc., flying between the United States and Europe, South America, and the Orient. During the past year all gust data that had been collected were transferred to punch cards to permit more efficient analysis.

Gust structure.—The investigation of the gust structure has been extended to determine the variations both with altitude and with direction. A reworking of the data obtained from flights below 17,000 feet has indicated that vertical and horizontal gusts are of about equal intensity in the atmosphere. More vertical than horizontal gusts appear to be present under thermally unstable atmospheric conditions, and under wind turbulence the conditions appear to be reversed.

Because the great mass of existing gust data has been obtained at relatively low altitudes, and because the newer aircraft reach their top speeds at higher altitudes, it has been necessary to obtain data on the variation of gusts with altitude. For this purpose an instrument called the G–Altitude (G–A) recorder has been developed to complement the well-known V–G recorder in service.

A further investigation in gust structure has been started by the procurement of an Army stratosphere airplane, and the necessary radiosonde equipment for making high-altitude soundings.

Lightning hazards to aircraft.—Data are being accumulated from air transport operators by means of a questionnaire on incidents of lightning strikes to airplanes. The data obtained from these questionnaires are being analyzed with a view to obtaining more information as to the extent to which electrical phenomena constitute a serious hazard to aircraft in flight especially with regard to their effect on flight personnel and the aircraft structure and equipment. Laboratory studies are also being conducted concerning the physical effects of high-voltage discharges on thin metal sheets through the cooperation of the General Electric Co. and the Westinghouse Electric & Manufacturing Co.

A study is being continued at the University of New Mexico, under the cognizance of the Special Subcommittee on Lightning Hazards to Aircraft, to determine the nature of electrical discharges in the atmosphere. In this work detailed information will be obtained on a large number of lightning strokes occurring during different parts of the year. Eight synchronized instruments capable of recording rapid changes in the electrical potential gradient at the surface of the earth distributed over a circular area approximately 5 miles in diameter will be used. It has been found that many electrical discharges are complicated by the fact that a large number of simple discharges between different charge centers may take place in succession, separated by time intervals of 1/100 second or more.

SUBCOMMITTEE ON SEAPLANES

During the past year the facilities of the NACA tank have been almost continuously in use for the study of specific problems and the testing of specific models submitted either by the military services or by manufacturers. In the latter category were two models of commercial transport seaplanes in which the Navy was interested, and two for use in connection with designs being prepared for the military services. The work was so urgent that NACA projects were carried on only to fill in between these tests; consequently, the only other model tested was one forming a part of the NACA program of research devoted to the development of improved forms of hulls for flying boats.

Plant and equipment.—The dynamically similar models used in investigations of the dynamic stability of seaplanes while taking-off and landing must accurately reproduce not only the form of the hull but also the aerodynamic structure (wings and tail surfaces). In these tests, the air in the tank should be perfectly still, corresponding as nearly as possible to the condition of take-off with no wind. Unfortunately, the towing carriage generates large turbulence and this turbulence in turn causes disturbance of the air well ahead of the carriage. A new auxiliary carriage made of steel tubing was constructed and put into service during the past year. This carriage was designed to give better air conditions and to improve the facility with which tests could be made. Although completely still air has not been obtained, there has been a considerable improvement.

The methods of constructing the very special dynamic models have been continuously improved, and the information gained from the test of each new model has been used to check the operation of the various features incorporated in it and to indicate the desirability of further changes. There have been almost no fundamental changes but many changes in detail.

Effect of angle of dead rise on resistance and drag.—The effect of the angle of dead rise of the bottom on the hydrodynamic resistance and the aerodynamic drag has been investigated on a series of three models of seaplane floats. The angles of dead rise investigated were 20°, 25°, and 30°.

Effects of chine flare on water resistance and spray.—The cross section of the bottom of most flying-boat hulls now shows a recurved portion, or flare, at the chine. Its primary purpose is to cause the wave coming from under the hull to be deflected and thus be kept from rising until it strikes the propellers or the wings, as it sometimes will if no such flare is provided.

Models of 22 flying-boat hulls were tested in the NACA tank for the purpose of determining the effect on water resistance and spray of 13 variations in the transverse section of the bottom of the forebody and 3 variations in the form of the bottom of the afterbody. The chine flare was found to reduce the height of the part of the spray that originated where the chine was above water level but did not reduce the height of the part of the spray that originated where the chine was below water level. The first type of spray comes from a sheet of water that travels across the bottom at high speed and may be termed a "velocity" spray. The second type is produced by water that escapes under the chine from the high pressure generated at the chine and may be termed a "pressure" spray. The chine flare causes an increase in the pressure on the bottom at the chine, and the addition of certain types of chine flares actually increases the height of this latter type of spray.

Study of the flow of water along the bottom of a model of a flying-boat hull.—Knowledge of the manner in which the water encountered by the bottom of a flying-boat hull moves over that bottom is of great value in understanding the effects of the various changes in form that are investigated. Observation of the flow, as it issues from beneath the bottom at the chines and the steps, indicated that changes in the direction of flow have marked effects on spray and resistance but, as long as it was possible to observe only the end effects, it was impossible to do much in the way of determining where the changes originated or what were the fundamental

causes. Obviously direct observation of the flow throughout the entire length of the bottom would give much valuable information. In order to verify this observation, a model with a transparent bottom was constructed.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

A number of requests have been received in the past year for comprehensive flutter studies of certain specific types of aircraft. Considerable computational information has been gained on the ternary cases or those with 3 degrees of freedom. This information throws light, in particular, on the important effects of structural friction and the need for obtaining dependable values for the damping parameters. The labor of the calculation methods for 3 or more degrees of freedom has been appreciably reduced, making it feasible to handle certain more complicated cases that may arise in tail-fuselage flutter. Further studies are now in progress on the influence of special effects associated with compressibility, finite span, floats, tabs, and higher-order modes.

The essential correctness and adequacy of the flutter theory for the prediction of critical speeds of wing flutter have already been demonstrated by numerous tests at the Committee's laboratory and elsewhere. The main problems are now in the technique of determining correct flutter parameters, and in the application of the theory to more unusual or complicated cases.

Tests on the ground.—Equipment for determining natural frequencies of airplanes on the ground has been improved and applied to a number of airplanes.

Tests of flutter models.—A large number of flutter tests have been made on models in the 8-foot high-speed tunnel. These investigations included tests showing the effect of compressibility upon flutter speed up to 500 miles per hour.

Wing frequencies.—Theoretical studies have been made of torsional and bending vibration of wings with particular reference to the effect of taper and of mass coupling upon the frequencies.

Damping.—The value of the structural damping parameter in an actual wing is being determined by tests on an outer wing panel mounted in the vacuum sphere. With the air pressure reduced to 1/20 of an atmosphere and the damping effect of the mounting and the instruments reduced to a minimum, the residual value of damping is attributed to the internal structural friction in the wing.

Propeller vibration.—Tests and theoretical studies are being made of the effects of shaft flexibility and rotation upon propeller-vibration frequencies and stresses. The effects of angle setting and chordwise flexibility upon the frequencies of a freely suspended propeller have been studied by means of models and theoretical analysis.

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REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

INCREASE IN ENGINE POWER

High octane number fuels.—The study of the relationship between maximum permissible engine performance and the knocking characteristics of aircraft-engine fuels has been continued under cognizance of the Subcommittee on Aircraft Fuels and Lubricants and is described in the report of that subcommittee.

Valve overlap.—An appreciable gain in engine power and a reduction in combustion-chamber temperatures can be obtained by operating with a large valve overlap. The effect of valve overlap on engine performance, when the inlet and the exhaust manifold pressures simulate those encountered when operating at altitude with mechanical and exhaust turbine-driven superchargers, has been investigated on a single-cylinder air-cooled engine. Performance tests were made over a range of inlet and exhaust pressures varying from 15 to 45 inches of mercury absolute.

The investigation of the performance of a multicylinder air-cooled engine, equipped with a special cam ring giving 130° of valve overlap, has been completed.

Piston rings.—One of the factors limiting the power output of aircraft engines is the failure of the piston rings to give satisfactory sealing and low wear. An investigation to determine the effect of various factors in piston-ring design on the operation of rings in high-output engines has been started. The factors investigated were: face, width, finish, and chemical treatment; side finish; and ring material.

Flow through poppet valves.—An investigation has been started to improve the flow coefficients of poppet valves. By an increase in the ratio of the outside to the inside diameter of the valve seats, the reconversion of kinetic energy to static pressure will be increased, and the pressure drop through the valves will be decreased. Tests have been made with steady flow through poppet-valve models having different seat widths, and the pressure drop has been determined. The effect of flaring the outer part of the passage between the valve and the cylinder head has also been determined.

Power recovery by jet propulsion.—An analysis has been made of the power recovered by discharging the exhaust gas rearward, from nozzles on the collector-ring exits, from separate exhaust stacks, and into the cooling duct behind the engine or radiator.

Two-stroke-cycle spark-ignition engine.—Research on the two-stroke-cycle, fuel-injection, spark-ignition engine has, during this year, been principally concerned with increasing maximum power. The liquid-cooled engine used in this investigation is a uniflow type having scavenging and charging air admitted to the cylin-

der through piston-controlled inlet ports with exhaust through four poppet valves in the head.

COMBUSTION RESEARCH

Knock.—The NACA high-speed motion-picture camera has been used to take an extensive series of photographs, at the rate of 40,000 frames per second, of normal combustion, preignition, and knock in the NACA combustion apparatus.

The N. A. C. A. combustion apparatus has also been used for a study of the knocking characteristics of several fuels that were available only in small quantities. The pressure and the temperature of the intake air were increased until a single charge of fuel injected into the cylinder resulted in knocking combustion. A complete range of fuel-air ratios was investigated, using inlet-air temperatures up to 300° F.

Preignition characteristics of fuels.—An investigation of the preignition characteristics of aircraft-engine fuels, made on the NACA combustion apparatus, has been concluded.

Air flow in engine cylinders.—The glass-cylinder engine has been modified to operate on a two-stroke cycle, with intake through ports in the cylinder wall and exhaust through four poppet valves in the head. Replaceable port bands, containing round ports of various sizes and having their axes inclined at various angles both horizontally and vertically, have been built.

Spark-plug temperatures.—A thermocouple installation has been designed for measuring the central electrode temperature of standard spark plugs and is now being used in the investigation of the knocking characteristics of aircraft-engine fuels.

FUEL CONSUMPTION

Safety fuel.—The performance of five new safety fuels having the same heating value as gasoline and relatively good antidetonating qualities has been investigated.

The antidetonating qualities of these fuels were investigated by comparing them with calibrated fuels in the same engine used for the performance tests. The tests showed that, by the addition of lead, the antidetonating qualities of these fuels could be increased to a point where the fuels could be used in most of the modern aircraft engines.

The effect of fuel-injection timing and injection-valve opening pressure on engine performance with safety fuels was investigated, and the performances of safety fuels with two types of injection-valve nozzles were compared.

HEAT TRANSFER ON LIQUID-COOLED ENGINES

An investigation is being made of the heat-transfer processes in a liquid-cooled engine using a number of coolants. From the results of tests in which ethylene glycol and water were the coolants, semiempirical equations have been derived relating cylinder-head temperatures to indicated horsepower, rate of coolant flow, and various physical properties of the coolant.

Heat-transfer coefficients.—A preliminary investigation of the heat-transfer properties of several liquids has been carried out with a laboratory apparatus built to approximate engine conditions. Experimental work has been completed that shows the effect of the ratio of length to diameter of an air passage on the value of the heat-transfer coefficient prevailing in the passage. Considerable increase in heat-transfer coefficient can be obtained by using smaller values of the length-diameter ratio in the air passages.

Heat-transfer process.—Tests to determine the heat-transfer process in a Wright Cyclone cylinder have been completed. The theory of engine-cylinder cooling developed in a previous report was further substantiated by the data obtained on the Cyclone cylinder. Equations for the average head and barrel temperatures of this cylinder, as functions of the engine and cooling conditions, were utilized to calculate the variation in cylinder temperature with altitude for level flight and climb. A method was presented for correlating average head and barrel temperatures and the temperatures at individual points on the head and the barrel obtained on the test stand and in flight. The method has been applied to the correlation and the comparison of data obtained on a number of service engines. Data were also obtained that showed the variation of cylinder temperature with time when the power and the cooling-pressure drop are suddenly changed.

Heat-transfer coefficients in flight.—Tests have been made to determine the heat-transfer coefficients of an electrically heated finned cylinder in flight. The object of the tests was to determine the heat transfer in flight and compare it with that obtained in the laboratory tests to determine best fin dimensions. The baffle arrangement around the cylinder in flight was similar to that used on modern radial engines. The results of the tests showed that the laboratory coefficients were about the same as the flight coefficients.

Engines in wings.—The necessity of reducing engine-nacelle drag has become increasingly acute owing to the gradual elimination of other sources of parasitic resistance. An obvious refinement for multiengine airplanes is the removal of the nacelles from the wings and enclosure of the complete power plant within the wing. An investigation has been started to determine the cooling requirements of aircraft engines completely enclosed in a wing and having the cooling air supplied by a blower.

Piston temperature.—As a part of the program for the study of piston cooling, tests were conducted on a single-cylinder, air-cooled carburetor engine, and the effect of

engine-operating conditions on the piston temperatures was determined.

Radiators.—The study of radiator design has been continued to determine the effect on design of placing limitations, such as fixing the frontal area, mass flow or pressure drop of cooling air, or length of tube in the air-flow direction. Formulas are being developed to make it possible to design the best radiator for conditions where any one of the quantities listed is fixed, also to give the maximum possible cooling efficiency obtainable under certain design limitations.

Experimental work is in progress to determine in detail the nature of flow through tube banks. The better understanding of flow across tubes being obtained as a result of this work may make possible some improvement in radiator design.

Oil coolers.—An analysis has been made of experimental oil-cooler data from commercial sources. Experimental work is in progress to determine heat-transfer data for use in oil-cooler design.

Intercoolers.—A mathematical analysis of conventional fin-type intercooler design has been made with a view to showing how to calculate the intercooler design that will use least power for specified cooling requirements.

The theoretical and the experimental investigations of a light-weight type of intercooler have been continued. Tests have been completed on a laboratory test unit, and the results show good agreement with theory.

VARIATION OF ENGINE POWER WITH ATMOSPHERIC CONDITIONS

Two formulas have been derived for predicting the power at altitude from sea-level tests; one for the case where the exhaust pressure equals the intake manifold pressure and the other for the case where the exhaust pressure is greater or less than the intake manifold pressure.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—The results of studies of the normal burning of mixtures of benzene, normal heptane, iso-octane, and carbon monoxide with oxygen and nitrogen were published by the Committee as Technical Report No. 682. The conclusions drawn in this report are applicable also to studies made subsequently with triptane as the fuel. The spherical bomb and auxiliary apparatus employed in this work are being modified for use at higher initial pressures.

The study of detonation and methods of detecting detonation has been continued. Several experimental indicators of detonation, using the principle of the spring-loaded ball, have been built. The most successful of these has been tested on the cylinders of several engines, showing considerable promise in each case. Further development is in the direction of making the device smaller and applicable to a wider variety of engines.

Flow characteristics of fuel lines.—Under the auspices of the Cooperative Fuel Research Committee, the Bureau has nearly completed an experimental study of the pressure drop across component parts of aircraft fuel systems as a function of size, design, and rate of gasoline flow.

Magnetos, testing and development.—Type tests were conducted on several types of magnetos.

A new altitude chamber was constructed for making electrical tests on aviation engine magnetos and other accessories.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Investigation of antiknock characteristics of fuels.—The investigation of the knocking characteristics of fuels in a liquid-cooled engine having a hemispherical combustion chamber has been continued. The data obtained with this cylinder, like results for other cylinders tested, show that the data on fuel knock can be correlated by plotting an end-gas density factor against an end-gas temperature factor. This investigation is to be continued using one of the latest types of air-cooled engine cylinders.

A study of the heat losses and the temperature rise of the surfaces of the combustion-chamber wall of an aircraft-engine cylinder has been made to determine the changes that occur when engine operation passes from normal nonknocking operation into knocking operation. Importance is attached to the behavior of the temperatures of the combustion-chamber surface when knocking occurs because of the danger of preignition and consequent engine failure. Contrary to expectations the data obtained show that, when moderate audible knock is encountered, the temperatures of the combustion-chamber surfaces do not rise abnormally fast. Such a result was also found for hot spots in the cylinder, such as spark-plug electrodes. The temperatures of the combustion-chamber surfaces that become new sources of ignition were found, however, to increase markedly and rapidly after surface ignition commenced. The tests with this cylinder show that the allowable knock rating is little affected by the average cylinder-wall temperatures. Likewise, hot-spot temperatures are little affected by average wall temperatures.

NATIONAL BUREAU OF STANDARDS

Investigation to develop nonleaded aircraft fuel of over 100 octane number.—This investigation, carried on for the past three years in cooperation with the National Advisory Committee for Aeronautics, the Army Air

Corps, and the Bureau of Aeronautics of the Navy Department, will be extended to include the examination of certain branched-chain paraffin hydrocarbons in the volatility range of aviation safety fuel.

Stability of aviation oils.—The study of the stability of aviation oils at the National Bureau of Standards during the last several years resulted in the development of a laboratory test for stability by means of which it is believed possible to predict both the changes which will occur in oils during operation in aircraft engines and the extent of deposits which are formed in these engines. A large number of engine inspections have been made during the year and information on the condition of these engines, as regards engine deposits, has been compared with laboratory data on the oils on which the engines were operated.

Ring sticking with aviation oils.—During the engine inspections made in connection with the study of oil stability, information was obtained concerning the extent of ring sticking.

Bearing corrosion.—In connection with the investigation of the corrosion of master-rod bearings, the study of the tendency of aviation oils to form corrosive acids has been continued.

Wear characteristics of aviation oils.—Considerable progress has been made at the National Bureau of Standards in the investigation of the wear characteristics of aviation lubricating oils. A satisfactory test procedure has been developed for the operation of the laboratory wear apparatus and data have been obtained on a number of reference oils. The effectiveness of a large number of compounding agents in reducing the amount of wear has also been determined.

Lubrication of master-rod bearings.—Considerable progress has been made on the investigation of master-rod bearing lubrication with the small bearing machine. The information obtained includes the frictional characteristics and heat-dissipation characteristics of bearings of one type of material. The operation covers a wide range of speeds and loads when using a number of oils of different viscosity grade at various oil-inlet temperatures and oil-feed pressures.

SPECIAL SUBCOMMITTE ON SUPERCHARGER COMPRESSORS

The ever-increasing demand for engines that can operate at a high power output over a large range of altitudes has greatly increased the importance of the problems connected with superchargers. With an increase in supercharging it is important that the supercharger operates efficiently in order that it will require a minimum amount of the engine power to compress the air to the desired pressure and that the heat of compression or the discharge air temperature will not be unduly increased. A high supercharger discharge air temperature is very objectionable for many reasons; it increases the load on the intercooler and the detonating propensity of the fuel and impairs the engine power because of the reduced weight of charge that can be inducted. An efficient supercharger also would be more reliable because the heat stresses would become a less important consideration for impellers operating at high tip speeds.

The Special Subcommittee on Supercharger Compressors was appointed to study means for improving the efficiency of centrifugal superchargers and is actively engaged on this problem.

SPECIAL SUBCOMMITTEE ON EXHAUST-GAS TURBINES AND INTERCOOLERS

The exhaust-gas turbine is an important device for recovering part of the energy available in the exhaust gases of internal-combustion engines. It has been found to be a useful means for driving the superchargers of aircraft engines and, with the increasing importance of superchargers, it has become equally important to increase the efficiency of the driving means.

With an increase in the output of supercharger compressors, it is necessary to prevent any increase in the temperature of the charge entering the engine cylinder in order to avoid detonation. The intercooler is a means for reducing the temperature of the charge after or during the compression process and becomes increasingly important as the heat of compression of the air in passing through the supercharger increases with the greater amount of work performed on each unit mass of air.

The Special Subcommittee on Exhaust-Gas Turbines and Intercoolers was appointed to study the means for improving the efficiency of exhaust-gas turbines and intercoolers, and is actively engaged on this problem.

REPORT OF COMMITTEE ON AIRCRAFT MATERIALS

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

Permanence of aircraft metals under continuous weathering.—Exposure tests of aircraft metals in sheet form were continued throughout the year. The tests covered commercial aluminum and magnesium alloys and various chromium-nickel ("stainless") steels under conditions of continuous exposure in a marine atmosphere and in atmospheric exposure with intermittent wetting with sea water at high tide. A report was issued by the National Advisory Committee for Aeronautics during the year summarizing the results of the first year's work and a similar one on the second year's results will appear soon. In addition, a general report summarizing results of tests covering a period of 10 years was published by the National Bureau of Standards as a research paper.

That portion of the test covering welded and riveted joints in the light alloys has yielded very definite and useful information as to the combination of metals which must be avoided in assembly work, both in the regular assembly joints and in the attachment of auxiliary parts to the main structure. In some unfavorable cases, heads of rivets may be completely disintegrated by the end of the first year, whereas, if the proper combination of metals is chosen, the rivets and adjoining metal are in excellent condition after exposure in a similar environment.

The tests on insulating materials for use between faying surfaces are in a relatively early stage. The results, however, have clearly shown the need for a more detailed study along this line, particularly when conditions permit the retention of a film of water in a crevice.

Some of the insulating materials used, or proposed for commercial use, were very inefficient.

In the exposure tests of sheet stainless steel, visual inspection of the specimens is usually sufficient to permit a rough rating of the materials. A more exact rating was obtained by flexural fatigue tests of specimens of the material in its initial state, and of companion specimens taken from the exposed sheet material. By this means it has been possible to evaluate quite accurately the relative corrosion damage on different stainless-steel compositions and also to differentiate between the corrosive effects in different environments.

Although discoloration of the spot welds by superficial rusting was evident on all materials after exposure, in no cases was the attack on the welds detrimental from the structural standpoint.

Elastic properties of high-strength constructional aircraft metals.—The second report in this investigation, summarizing the data on the effect on the tensile elastic properties of plastic deformation (cold working) and of heat treatment, is now in press. The beneficial effect of heat treatment of stainless steel, especially with respect to its elastic properties, is especially noteworthy. With the completion during the year of the study of elastic properties of the metals at low temperatures, the phase of the investigation on tensile elastic properties was completed. The assembling of the report on this part of the investigation has been practically completed. The dearth of information on torsional elastic properties of the metals used in tubular form in aircraft construction prompted the extension of the investigation in this direction. The materials necessary for this study have been assembled and the work is scheduled to start in the near future.

Protective treatment of magnesium.—It is well recognized that corrosion is a controlling factor which determines the length of useful life of magnesium as a structural material, especially in a marine environment. Initial surface treatment is therefore very important for this class of metals. As yet no thoroughly satisfactory method of treatment has been developed for magnesium alloys, as has been done for the aluminum alloys.

Aircraft metals at subzero temperatures.—The results of the extensive recent series of tests in this field have been assembled and coordinated and are available to designers and manufacturers. They will be published ultimately as a research paper of the National Bureau of Standards.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

Development of plastic material for aircraft structures.—The experimental work on the development of reinforced plastics suitable for aircraft construction is now proceeding along three main lines.

The first phase involves the synthesis of phenolic resins from various raw materials, such as phenol, cresols and xylenols on the one hand and formaldehyde, acetaldehyde, and furfural on the other, and determining the relationship which exists between the composition and the properties of these resins. It has been observed in work with the birch veneers that maximum-strength values are obtained when the modulus of elasticity of the resin binder is similar to that of the wood. This should also be true of other types of laminated products. Hence, this work on the properties of pure synthetic resins should make possible the selection of resins suitable for use with whatever type of reinforcing agent is found to be desirable in molding aircraft structures.

The second phase of the experimental program involves further investigation of a number of reinforcing materials. Various types of paper, cloth, wood veneers, fibers, and thin metal wires and sheets have been made into laminated panels and their properties determined. Optimum arrangement of these various elements in a composite structure, and determination of the minimum temperature and pressure necessary to obtain proper bonding of the reinforcing agents, are the ultimate objectives of this work. Commercial resins and resins synthesized in the laboratory at the Bureau of Standards are being used in this work.

The third phase of this investigation involves the determination of the pertinent physical properties of those reinforced plastics which indicate possibilities for use for aircraft construction. Materials submitted from commercial sources, as well as those prepared in the laboratory at the National Bureau of Standards, have been examined, and such properties as tensile strength, compressive strength, flexural strength moduli of elasticity in tension, compression and flexure, shear strength, impact strength, bearing strength, water ab-

sorption, and specific gravity have been measured, and these data are being incorporated into a report. Particular attention is being directed at the present time to determining the moduli of elasticity and the coefficients of thermal expansion of the resins and reinforcing agents, in order that these materials may be matched up as closely as possible with respect to these properties.

Evaluation of transparent plastics as windshields for aircraft.—In previous reports of work on transparent plastics, it was noted that accelerated aging tests made with apparatus employing an enclosed carbon arc as the source of ultraviolet light failed to correlate well with the results of outdoor exposure. A detailed investigation of accelerated weathering of transparent plastics was therefore undertaken to obtain a reliable test for rapid evaluation of weathering properties.

The effects of different laboratory accelerated-weathering conditions upon various types of transparent plastics were evaluated by measurements of light transmission and haze, and by visual examination of the specimens for crazing, fusing, blooming, discoloration, and warping. These results were compared with data obtained for specimens of the same plastics exposed to the weather in Washington, D. C. On the basis of these tests, a method of accelerated weathering of transparent plastics has been developed which gives results correlating well with the actual behavior of the materials in outdoor exposure tests.

REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

STRUCTURAL RESEARCH

The structural research conducted under the supervision of the Committee on Aircraft Structures is concerned with both the theoretical and the experimental approach. Wherever possible each problem is attacked by both methods in order to obtain sound and proved formulas for use in stress analysis and design. Some of the structural problems on which progress has been made during the past year are discussed in the following paragraphs.

Rib design.—One of the structural problems that has been quite generally overlooked in the past by engineers is the design of intermediate frames and ribs in stressed-skin structures. The work on this subject, reported last year, has been greatly extended both theoretically and experimentally.

Diagonal-tension beams.—In practical design where diagonal-tension beams are encountered, it is usually found that the beam lies in a region somewhere between a shear-resistant web and a completely developed diagonal-tension field. In order to supply information on the transition region between these two extreme conditions, a special investigation of the incompletely developed diagonal-tension field beam was undertaken.

Stress distribution in monocoque structures.—The shear deformation of monocoque structures is such as to cause the stress distribution to differ considerably, in many cases, from that given by the ordinary theory of bending. Consequently, for a proper analysis of stressed-skin structures, the effect of this shear deformation must be considered. Technical Note No. 739 presents a convenient method of solving this problem by the method of dividing the beam into a number of bays that can be assumed to have constant cross section and loading. The solution is particularly well adapted to beams of variable cross section and loading. The recurrence formula given in the paper is analogous in form to the well-known three-moment equation of beams.

Photoelastic analysis of three-dimensional stress systems.—During the past year a photoelastic analysis of three-dimensional stress systems was made by utilizing the polarization phenomena associated with the scattering of light. By this method, the maximum shear and the directions of the three principal stresses at any point within a model can be determined, and the two principal stresses at a free-bounding surface can be separately evaluated. Polarized light is projected into the model through a slit so that it illuminates a plane section. The light is continuously analyzed along its path by scattering and the state of stress in the illuminated section is obtained. By means of a series of such sections, the entire stress field may be explored. The method was used to analyze the stress system of a simple beam in bending. The results were found to be in good agreement with those expected from elementary theory. This work is presented in Technical Note No. 737.

Local instability of compression members.—During the past year one paper (Technical Note No. 743) has been prepared wherein charts are presented for the coefficient in the formula for critical compressive stress at which cross-sectional distortion begins in columns with I-sections, Z-sections, channel sections, and rectangular-tube sections.

Torsional instability of columns.—Until recent years little progress had been made in developing the theory of torsional failure of columns.

Before proceeding with further theoretical analyses on torsional instability of columns, the Committee considered it desirable to make a careful experimental investigation of the subject. Arrangements were made to have the tests conducted by Professor Niles at Stanford University. These tests were completed during the past year and the results are presented in Technical Note No. 733. The results of the tests that were made on channel section columns tend to validate the theoretical formulas developed by the Committee.

As a consequence of this experimental investigation the Committee is now proceeding to work out theoretical formulas on torsional instability of columns in a practical form for designers. Where these formulas give a lower critical stress than the ordinary column formulas, failure can be expected to occur by torsional instability.

Compressive strength of sheet-stiffener panels.—An extensive investigation of the compressive strength of sheet-stiffener panels was made under contract by the California Institute of Technology and the results are reported in Technical Note No. 752.

STRUCTURAL LOADS ON AIRPLANES

The Committee, in cooperation with the Civil Aeronautics Authority, instituted a program during the past year of installing V–G recorders in all large airplanes and in the smaller types of airplane as they were produced and put into service. In line with this program a few flight records were obtained on the Boeing S–307 Stratoliner during the early flight tests and more recently in regular scheduled operation on the air transport lines.

Gust tunnel.—Some time has been spent during the past year in improving the accuracy of the gust tunnel and in developing a method of recording the wing deflections of the airplane models as they traverse the gust tunnel.

The results of tests of a gust-alleviating flap which have been previously mentioned, have been analyzed and published in Technical Note No. 745. The analysis indicated that the reduction in acceleration due to the flap could be calculated with a fair degree of accuracy.

Tests in the gust tunnel on a model of a canard airplane, which were reported last year, have since been published in Technical Note No. 758.

An investigation of the effect of the stability of an airplane on the gust-load factor is now in progress. In this investigation the gust shape and the various stability parameters are being varied to determine their effect on the load factor. A series of calculations on the effect of stability is being made concurrently to complete the investigation.

Dynamic overstress.—During the past year calculations of the reactions of an airplane with a flexible wing have been made for a large number of cases. Calculations were made on the basis of the previously verified assumption that the actual damping under rapidly changing conditions is equivalent to a constant proportion of the ideal damping for steady-flow conditions. The calculations indicate that, except for the sharpest gusts, the stress in the wing is equal to or less than that for static conditions. The results also show that the accelerations at the wing tip will be two to three times the acceleration in the fuselage for sharp gusts and will decrease to unity for the larger gust-gradient distances.

In order to investigate the accuracy of the calculations, a series of tests on an airplane model with a flexible wing is in progress in the gust tunnel.

Load distribution.—The analytical study of the variation of the net wing loads under conditions of combined normal and angular accelerations has been published in Technical Note No. 757. This study included the shear and the moment variation due not only to one-wheel landings but also to aileron deflections in flight.

Measurements of the pressure distribution over a single rib of an airplane diving at speeds in excess of 550 miles per hour have been made.

Tail loads.—The study of tail loads has been continued along the lines indicated in the last annual report of the Committee. The analytical report giving the results of the study of factors affecting the tail loads has been completed. The supplementary flight tail-load program, in which the tail of a small airplane was mounted on calibrated springs and in which conditions of elevator movement were rigidly controlled, has been completed. The evaluation of the data is now nearly completed.

Loads on seaplane hulls.—The evaluation of the large amount of pressure, stress, and acceleration data taken in the flight tests of the two large flying boats mentioned in the last annual report has been completed. The results from these investigations are, in general, in reasonable agreement, although individual impacts show wide variation in the loads. It appears that the relative severity of rough-water and smooth-water impacts is principally due to differences in the distribution of water load over the bottom.

The survey of the available literature on the theory of landing impacts, which is a part of the research program for understanding the processes involved in the landing impact, has been completed. The impact theory is applied to numerous cases in which actual impact data are available. The checks obtained are such that, if isolated, they would seem to corroborate the theory. The need for an impact basin is indicated.

NATIONAL BUREAU OF STANDARDS

The work on aircraft structures has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

Tensile and compressive stress-strain graphs of thin sheet metal.—With the development of the pack test, a large amount of data on compressive, as well as tensile, properties of thin sheet metal for aircraft has been accumulated at the National Bureau of Standards.

Strength of flush-riveted joints.—The program on static tests of flush-riveted joints has been extended to in-

clude single-rivet and multiple-rivet joints fabricated by the principal aircraft manufacturers, each manufacturer using his own type of joint and riveting technique.

Aging of aluminum rivet alloys.—Data on the increase in strength with aging of riveted joints and rivet wire were acquired as a byproduct of the investigation of riveted joints. Curves were obtained on four commonly used aluminum rivet alloys for the increase, with aging time up to 2½ years, of tensile and shearing strength of rivet wire, shearing strength of riveted joints, and driving stress required to form a standard cone-point head.

Aircraft tubing.—The second portion of the program on high-strength chromium molybdenum steel tubing of the type used in landing gears was completed by tests of 15 tubes with D/t ratios from 12 to 34 under combined axial and bending loads. The results indicate the errors involved in computing the strength of these tubes under combined load by various methods of interpolation between the strength under pure axial load and pure bending load.

Flat plates under normal pressure.—The program of normal pressure tests of flat plates has been completed with a report on rectangular plates. It was found that all results for rectangular plates with clamped edges could be plotted on a dimensionless basis to give an empirical relation between the washboarding pressure, i. e., the pressure at which yielding begins, the dimensions of the plate, and the tensile properties of the material.

Sheet-stringer panels.—End compression tests have been carried out on six spot-welded aluminum-alloy sheet-stringer panels which were identical except for a variation in spot-weld spacing from ½ to 4 inches between centers. Three of the panels failed by separation of spot welds at a stress appreciably below that for failure by stringer instability. The remaining three panels failed by stringer instability at a stress in agreement with an empirical chart prepared on the basis of tests on riveted panels.

Monocoque box under transverse load.—The second and third portions of the program of tests on monocoque boxes were completed with a stress survey of a monocoque box specimen under pure bending loads and cantilever bending loads. At low loads the strain distribution in the center portion of the box was found to agree closely with that calculated from the simple beam theory. Buckling of the sheet between stringers occurred at a stress in agreement with that observed in the end compression test described in Technical Note No. 721.

Fatigue tests of aluminum-alloy wing beams.—Axial fatigue tests of wing beams by the resonance method were continued with tests on additional specimens. These tests were run at relatively low stress amplitudes in order to obtain points on the stress versus cycles-to-failure curve which would indicate the fatigue limit of the assembled structure.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915, and the membership increased from 12 to 15 by act approved March 2, 1929 (U. S. C., title 50, sec. 151). Its membership is appointed by the President and consists of two representatives each of the War and Navy Departments from the offices in charge of military and naval aeronautics, two representatives of the Civil Aeronautics Administration (Civil Aeronautics Act of 1938), one representative each of the Smithsonian Institution, the United States Weather Bureau and the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter six serve for terms of 5 years. All the members serve as such without compensation. During the past year the following changes occurred in the membership of the main Committee:

The term of office of Col. Charles A. Lindbergh expired December 1, 1939, and, pursuant to his own request, he was not reappointed.

To succeed Colonel Lindbergh, the President appointed Brig. Gen. Walter G. Kilner, United States Army, retired, formerly Assistant Chief of the Army Air Corps, for the 5-year term expiring December 1, 1944. General Kilner resigned on March 12, 1940, because of the fact that he had accepted a position with one of the aircraft manufacturers.

To fill the vacancy caused by General Kilner's resignation, the President, on March 26, 1940, appointed Dr. Robert E. Doherty, president of the Carnegie Institute of Technology, Pittsburgh, Pa., to serve the remainder of the term expiring December 1, 1944.

Hon. Clinton M. Hester, Administrator of Civil Aeronautics, on August 2, 1940, submitted his resignation as a member of the Committee as a representative of the Civil Aeronautics Authority, because of his retirement from his post as Administrator of Civil Aeronautics.

On September 5, 1940, the President appointed Col. Donald H. Connolly, Administrator of Civil Aeronautics, a member of the Committee to succeed Mr. Hester to serve as one of the two representatives of the Civil Aeronautics Administration provided by law.

Under the rules and regulations governing the work of the Committee, as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee. On October 19th, 1939, Dr. Vannevar Bush was reelected Chairman and Dr. George J. Mead was reelected Vice Chairman of the main Committee. Dr. Bush was also reelected Chairman of the Executive Committee and Dr. Charles G. Abbot was reelected Vice Chairman of the Executive Committee.

The executive offices of the Committee, including the office of aeronautical intelligence and the office of aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. It serves as the depository and distributing agency for the scientific and technical data on aeronautics comprising the results of fundamental Committee researches and also the scientific and technical information collected by the Committee from governmental and private agencies in this country and abroad. The data collected are classified, catalogued, and disseminated by this office.

On June 3, 1940, the headquarters of the Committee's technical assistant in Europe, Mr. John J. Ide, were transferred temporarily from the American Embassy in Paris to the American Legation at Berne, Switzerland. On June 14, 1940, the activities of the office of the technical assistant in Europe were suspended by the Committee, and Mr. Ide returned to the United States by air from Lisbon in July 1940.

RESEARCH FACILITIES

Langley Field, Va.—With the consistent support of the President and of the Congress, the Committee has developed at Langley Field, Va., a large and well-equipped aeronautical research laboratory, known as the Langley Memorial Aeronautical Laboratory.

At the present time, the Langley Field laboratory comprises the following units: The 8-foot, 500-mile-per-hour wind tunnel; the full-scale wind tunnel with a throat 60 by 30 feet; a 19-foot pressure wind tunnel; the 20-foot propeller-research tunnel; the 5-foot variable-density wind tunnel; a 7- by 10-foot wind tunnel; a 4- by 6-foot vertical wind tunnel; a 15-foot free-spinning wind tunnel; a 12-foot free-flight wind tunnel;

a refrigerated wind tunnel with a throat 7½ by 3 feet; two high-velocity jet-type wind tunnels of 11- and 24-inch throat diameters, respectively; the 2,900-foot NACA tank; an engine research laboratory; a flight research laboratory; an instrument laboratory; and administration, shop, and service buildings. The research facilities at Langley Field also include the following recent additions: A structures-research laboratory and a two-dimensional flow wind tunnel.

The Committee is proceeding to construct at Langley Field a stability wind tunnel, a 16-foot high-speed wind tunnel, a 20-foot free-spinning wind tunnel, a second seaplane-towing tank, an electric power generating plant, and extensions to the NACA hangar and administration building.

Moffett Field, Calif.—The Committee has in process of construction at Moffett Field, Calif., a second major research station, authorized by act approved August 9, 1939, at a total cost of not to exceed $10,000,000. Of this amount $6,090,980 has been appropriated by the Congress.

The laboratory was named on April 18, 1940, with the approval of the President, the Ames Aeronautical Laboratory in honor of Dr. Joseph S. Ames, past Chairman of the Committee and President Emeritus of the Johns Hopkins University at Baltimore, Md. Dr. Ames was one of the original members of the National Advisory Committee for Aeronautics appointed by President Wilson in 1915 and had served continuously for over 24 years as a member, including 20 years during which he was either Chairman of the main Committee or Chairman of its Executive Committee.

At the present time the Ames Aeronautical Laboratory comprises the following units: A flight-research laboratory and a shop building. The Committee is proceeding to construct a 16-foot wind tunnel, two 7- by 10-foot wind tunnels, a stock and utilities building, a science laboratory, an administration building, and other wind tunnels.

The Committee will conduct its research activities at this laboratory under a status similar to that under which it functions at Langley Field.

THIRD RESEARCH STATION

Reference was made in the previous annual report to the recommendation of the Special Survey Committee on Aeronautical Research Facilities, which, on October 19, 1939, recommended, "that an engine research laboratory be constructed at the earliest possible date." That committee was composed of Col. Charles A. Lindbergh, chairman; Maj. Gen. Henry H. Arnold, Chief of the Army Air Corps; Rear Admiral John H. Towers, Chief of the Bureau of Aeronautics, Navy Department; and Hon. Robert H. Hinckley, Chairman of the Civil Aeronautics Authority. The main committee immediately appointed a Special Committee on Engine Research Facilities to advise with the Director of Aeronautical Research and submit recommendations with regard to the scope of the proposed new engine research laboratory. This Special Committee on Engine Research Facilities was composed of the following:

Dr. George J. Mead, Chairman.
Commander Rico Botta, United States Navy.
Mr. Frank W. Caldwell, Hamilton Standard Propellers.
Mr. R. M. Hazen, Allison Engineering Company, Division of General Motors Corporation.
Mr. S. D. Heron, Ethyl Gasoline Corporation.
Mr. L. S. Hobbs, Pratt & Whitney Aircraft Corporation.
Mr. Carlton Kemper, Langley Memorial Aeronautical Laboratory.
Mr. Gaylord W. Newton, Civil Aeronautics Authority.
Mr. Arthur Nutt, Wright Aeronautical Corporation.
Maj. E. R. Page, Air Corps, United States Army.

The report of the Special Committee on Engine Research Facilities, dated January 23, 1940, presented a complete detailed plan for the equipment of the proposed engine research laboratory. This report was approved by the main Committee on February 7, 1940, and a supplemental estimate of appropriation was submitted to the Bureau of the Budget on March 7, 1940. After careful study in the Bureau of the Budget, the project was approved by the President and submitted to the Congress on May 20, 1940 (House Doc. No. 777, 76th Cong., 3d sess.).

After hearings before the House Appropriations Committee, the aircraft engine research laboratory was authorized by the Congress in the "First Supplemental National Defense Appropriation Act, 1941," approved June 26, 1940. That act appropriated $2,000,000 and carried contract authorization to a total of $8,400,000 for the construction and equipment of the proposed laboratory, including acquisition of a site to be selected by the committee. Seventy-two sites for the proposed laboratory were brought to the attention of the committee and were referred to a Special Committee on Site, consisting of Dr. Vannevar Bush, chairman, Dr. Lyman J. Briggs, Maj. Gen. George H. Brett, Army Air Corps, Capt. Sidney M. Kraus, United States Navy.

The Special Committee on Site determined the considerations to be evaluated and approved a schedule of weights. The characteristics of each of the seventy-two sites, as described in the proposals and as supplemented by interviews and inquiries, were subjected to careful analysis. The elements that were evaluated included the size, status and amount of air traffic on the flying field; the area available; the character of the soil; the acceptability of the site; water and sewage connections; vulnerability to air attack; adequacy and cost of electric power; proximity to a suitable industrial center; accessibility to the aircraft engine industry; accessibility to centers of scientific and technical activ-

ity; composition, cost, and quantity of water; climate and weather; and living and working conditions for employees.

A careful analysis of the sites offered impressed the committee with the fact that the proposed laboratory could be effectively operated in any one of a number of cities. A Special Subcommittee on Site Inspection was therefore appointed consisting of:

John F. Victory, chairman.

Capt. Donald J. Keirn, Air Corps, United States Army, Wright Field, Dayton, Ohio.

Lt. Comdr. John M. Rutherfurd, United States Navy, Bureau of Aeronautics.

Mr. Russell G. Robinson, of the Committee's engineering staff.

A total of 37 cities or localities was visited and inspections made of from 1 to 4 sites in each place. The reports on inspections were made without recommendations and were carefully considered by the Special Committee on Site. As additional information was received by mail and by interview it was incorporated in the record of each site. The Special Committee on Site, after five meetings and most careful consideration of all factors, made a unanimous recommendation to the main Committee, and the latter, after carefully reviewing the methods used and the evidence, and after prolonged discussion and questions, unanimously approved the report and recommendation of the Special Committee on Site to the effect that the site at the municipal airport at Cleveland, Ohio, was in its combination of advantages the site for the aircraft engine research laboratory that would best serve the nation's interests.

This decision was announced on November 25, 1940, and immediately the Committee started advertising for bids on construction.

The site selected consists of approximately 200 acres fronting on a first-class municipal airport and backed by a metropolitan park. The cost of the land is $500. The Committee will proceed with construction of the laboratory as rapidly as possible.

COOPERATION WITH THE AVIATION INDUSTRY

In the formulation of its research programs, the Committee includes provision for the problems of aeronautical research which are of particular importance to the aviation industry, in connection with both the design and operation of aircraft. The representatives of the industry refer their problems of this nature to the Committee as they arise, either by correspondence or through personal contact. The Committee avails itself of every opportunity to obtain suggestions and recommendations from representatives of the aircraft manufacturers and operators as to investigations which are deemed of special importance.

Because of the great increase in the number and importance of urgent research problems under investigation by the Committee and the greatly increased pressure of work resulting from the effort required in the design and construction of new research facilities, the Committee this year found it necessary to postpone its annual conference with representatives of the aircraft industry usually held at its laboratory at Langley Field, Va. In order to insure that this posponement would not result in depriving the industry of the Committee's assistance in the solution of urgent and important problems, the Committee arranged for the various aircraft manufacturers separately to send their representatives to the Langley Field laboratory for conferences with members of the Committee's staff to discuss important problems.

Realizing that frequently the value of information is greatly enhanced by its prompt availability, the Committee makes every effort to place the results of its researches at the earliest possible date in the hands of those units of the industry which have been designated by the Army or Navy to receive restricted or confidential information. It sometimes appears, in the course of an extensive investigation being conducted by the Committee, that the results so far obtained will be of special interest and value to the aircraft industry if made available immediately. In such cases the Committee issues the information in advance confidential form.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the inventions section received correspondence relating to about 2,650 inventions and designs pertaining to the aeronautical art. All of these proposals were given careful consideration and evaluated. The necessary correspondence was conducted to advise the submitters of the evaluations and interviews were granted inventors to discuss new proposals and their merits.

COORDINATION OF AERONAUTICAL RESEARCH

As recommended by a special committee appointed in 1939 to study the problem of coordination of all aeronautical research activities in the United States, a

Coordinator of Research, Mr. S. Paul Johnston, was appointed January 9, 1940. A coordination office was set up in the Committee's headquarters in Washington, and provisions made for a resident coordination representative on the West Coast. In order to maintain close contact with manufacturers and in order to keep in touch with all organizations, governmental and private, that operate research facilities, the coordination staff has during the year made approximately the following number of visits:

75 visits to schools and universities.
130 visits to aircraft manufacturers.
30 visits to aircraft engine manufacturers.
65 visits to miscellaneous accessories and materials manufacturers.
10 visits to governmental laboratories (other than NACA).

This work has not been restricted to any particular area in the United States but has included every locality where anything of significance in aeronautical progress is known to be under way. Reports submitted to the laboratory by the coordination staff in the field have been extremely valuable in providing closer contacts between the research personnel of the NACA and the aircraft and engine industries.

A number of special problems are being handled through the Coordination Office. Among them are: (*a*) A spot-welding research program on aluminum alloys in cooperation with the Army, the Navy, the National Bureau of Standards, and the Welding Research Committee; (*b*) an analysis of engine power ratings and engine accidents in cooperation with the C. A. A., and the National Defense Advisory Commission; (*c*) an investigation of current design practice with respect to ducting for cooling engines and power plant accessories, (*d*) a survey of current opinion and practice in the industry regarding standardized and interchangeable power plant assemblies; (*e*) a continuation of the investigation of the use of plastic materials and plastic bonded plywoods for the Army and Navy, in cooperation with the National Bureau of Standards, the Forest Products Laboratory, and other Government agencies. Where it seemed desirable, conferences have been arranged at various places, including the Langley Field laboratory, and arrangements have been made frequently for laboratory personnel to visit industry units on special problems of urgent interest to national defense.

AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

One of the main duties with which the Coordinator of Research is charged is the utilization to the maximum advantage to the United States of available research facilities in educational and scientific institutions. Early in 1940 an extensive survey was made by a questionnaire of educational institutions in the United States that were known to have facilities that had any bearing on aeronautical research. There is now on file in the Washington office full information on the equipment and personnel of some 75 schools. Many of these schools have been visited personally by the Coordinator or his staff as a check on the material submitted in response to the questionnaire.

During the course of the year, suggestions have been solicited from Government agencies and from the aircraft and engine industries for research problems suitable for university laboratory allocation. Although many proposals for research are still being initiated by universities, it is the policy of the coordination division to suggest to such private laboratories problems that fit into the requirements of the Government.

With funds available under the 1941 appropriations, some 30 research projects have been set up in various university laboratories, subdivided as follows:

	Projects
Aerodynamics	6
Structures	10
Materials	5
Power plants	9

A number of proposals are now under consideration by the various subcommittees, which, by January 1941, will absorb the entire balance of funds available for the current fiscal year. In view of the large number of research projects that have bearing on the defense programs, increased appropriations for the support of research in scientific and educational institutions have been requested for the fiscal year 1942.

SUBCOMMITTEES

The National Advisory Committee for Aeronautics has organized standing technical committees, with subcommittees, for the purpose of coordinating the research needs of aviation and preparing research programs in their respective fields. The four main technical Committees on Aerodynamics, Power Plants for Aircraft, Aircraft Materials, and Aircraft Structures, with their subcommittees, recommend the programs for aeronautical research conducted by the Committee's laboratories and those conducted by other agencies. Under the Committee on Aerodynamics two additional standing subcommittees have recently been organized to provide for studies in particular fields of aerodynamic research, namely, the Subcommittee on Propellers for Aircraft and the Subcommittee on Rotating-Wing Aircraft.

As previously stated, it is the policy of the Committee to establish from time to time special technical subcommittees for the study of particular problems as they arise. To meet the increasing needs of the military services and the industry, three new special subcom-

mittees have been appointed during the past year under the Committee on Power Plants for Aircraft. These are the Subcommittees on Supercharger Compressors, Exhaust-Gas Turbines and Intercoolers, and Induction-System De-Icing.

The work of the standing and special technical committees and subcommittees has been described in part I. The organization of all the Committee's subcommittees is as follows:

COMMITTEE ON AERODYNAMICS

Dr. Edward Warner, Chairman.
Mr. Edmund T. Allen, Boeing Aircraft Co.
Maj. Howard Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
Lt. Col. Franklin O. Carroll, Air Corps, United States Army, Matériel Division, Wright Field.
Mr. Charles H. Chatfield, United Aircraft Corporation.
Commander Walter S. Diehl, United States Navy.
Dr. Hugh L. Dryden, National Bureau of Standards.
Mr. John Easton, Civil Aeronautics Administration.
Mr. J. T. Gray, Civil Aeronautics Administration.
Mr. Eastman N. Jacobs, National Advisory Committee for Aeronautics.
Mr. S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Prof. Otto Koppen, Massachusetts Institute of Technology.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Dr. Clark B. Millikan, California Institute of Technology.
Mr. Robert R. Osborn, Vultee Aircraft, Inc.
Commander F. W. Pennoyer, Jr., United States Navy.
Mr. H. J. E. Reid, National Advisory Committee for Aeronautics.
Mr. Fred E. Weick, Engineering and Research Corporation.
Mr. John B. Wheatley, The Glenn L. Martin Co.
Mr. Theodore P. Wright, Curtiss-Wright Corporation.

SUBCOMMITTEE ON AIRSHIPS

Dr. J. C. Hunsaker, Chairman.
Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.
John Easton, Civil Aeronautics Administration.
Capt. Garland Fulton, United States Navy.
Lt. Col. C. F. Greene, Air Corps, United States Army, Matériel Division, liaison officer at NACA Laboratory.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Dr. F. W. Reichelderfer, Chairman.
Col. E. S. Gorrell, Air Transport Association of America.
Dr. W. J. Humphreys, United States Weather Bureau.
Dr. J. C. Hunsaker, Massachusetts Institute of Technology.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
R. W. Knight, Civil Aeronautics Adminstration.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Delbert M. Little, United States Weather Bureau.
Dr. Charles F. Marvin, Washington, D. C.
Capt. Arthur F. Merewether, Air Corps, United States Army.
Lt. Comdr. Howard T. Orville, United States Navy.
Mr. Richard V. Rhode, National Advisory Committee for Aeronautics.
Dr. C. G. Rossby, United States Weather Bureau.

SPECIAL SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

Delbert M. Little, United States Weather Bureau, Chairman.
Dr. O. H. Gish, Carnegie Institution of Washington.
Lt. Comdr. Robert S. Hatcher, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
K. B. McEachron, General Electric Co.
Irving R. Metcalf, Civil Aeronautics Administration.
E. J. Minser, Transcontinental & Western Air, Inc.
Captain C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. F. B. Silsbee, National Bureau of Standards.

SUBCOMMITTEE ON SEAPLANES

Dr. J. C. Hunsaker, Chairman.
Theophile dePort, liaison office at NACA Laboratory.
Commander W. S. Diehl, United States Navy.
J. T. Gray, Civil Aeronautics Administration.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Captain C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
A. L. Morse, Civil Aeronautics Administration.
Captain H. C. Richardson, United States Navy.
Starr Truscott, National Advisory Committee for Aeronautics.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

H. J. E. Reid, National Advisory Committee for Aeronautics, Chairman.
Capt. Frederick R. Dent, Jr., Air Corps, United States Army, Matériel Division, Wright Field.
Commander W. S. Diehl, United States Navy.
Lt. Comdr. Robert S. Hatcher, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.
H. D. Hoekstra, Civil Aeronautics Administration.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Irving R. Metcalf, Civil Aeronautics Administration.
Dr. Walter Ramberg, National Bureau of Standards.
Lt. Albert B. Scoles, United States Navy.
Benjamin Smilg, Matériel Division, Army Air Corps, Wright Field.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

SUBCOMMITTEE ON PROPELLERS FOR AIRCRAFT

Frank W. Caldwell, Hamilton Standard Propellers, Chairman.
David Biermann, National Advisory Committee for Aeronautics.

Maj. Howard H. Couch, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. Hugh L. Dryden, National Bureau of Standards.
Mr. Louis H. Enos, Curtiss Propeller Division.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Erle Martin, Hamilton Standard Propellers.
John C. Morse, Civil Aeronautics Administration.
Lt. Wallace B. Mechling, United States Navy.
Mr. Fred E. Weick, Engineering and Research Corporation.

SUBCOMMITTEE ON ROTATING-WING AIRCRAFT

John Easton, Civil Aeronautics Administration, Chairman.
Mr. Frederick J. Bailey, Jr., National Advisory Committee for Aeronautics.
Commander Walter S. Diehl, United States Navy.
Capt. V. R. Haugen, Air Corps, United States Army.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Prof. Alexander Klemin, Daniel Guggenheim School of Aeronautics, New York University.
A. E. Larsen, Pitcairn Autogiro Co.
W. Laurence Le Page, Platt-Le Page Aircraft Co.
Dr. G. W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
R. H. Prewitt, Kellett Autogiro Corporation.
I. I. Sikorsky, Vought-Sikorsky Aircraft.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Dr. George J. Mead, Chairman.
Arthur Nutt, Wright Aeronautical Corporation, Vice Chairman.
Commander Rico Botta, United States Navy.
Frank W. Caldwell, Hamilton Standard Propellers.
Dr. H. C. Dickinson, National Bureau of Standards.
R. M. Hazen, Allison Engineering Company.
S. D. Heron, Ethyl Gasoline Corporation.
L. S. Hobbs, Pratt & Whitney Aircraft.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Carlton Kemper, National Advisory Committee for Aeronautics.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Gaylord W. Newton, Civil Aeronautics Administration.
Lt. Col. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.
Prof. E. S. Taylor, Massachusetts Institute of Technology.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

W. G. Whitman, Massachusetts Institute of Technology, Chairman.
S. D. Heron, Ethyl Gasoline Corporation, Vice Chairman.
Dr. D. P. Barnard, Standard Oil Co. of Indiana.
T. A. Boyd, General Motors Corporation.
H. K. Cummings, National Bureau of Standards.
Dr. G. H. B. Davis, Standard Oil Development Company.
Lt. Henry R. Dozier, United States Navy.
Dr. J. Bennett Hill, Sun Oil Co.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Robert V. Kerley, Matériel Division, Army Air Corps, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Gaylord W. Newton, Civil Aeronautics Administration.
Addison M. Rothrock, National Advisory Committee for Aeronautics.

SPECIAL SUBCOMMITTEE ON SUPERCHARGER COMPRESSORS

Val Cronstedt, Pratt & Whitney Aircraft, Temporary Chairman.
Rudolph Birmann, Turbo Engineering Corporation.
R. S. Buck, Pratt & Whitney Aircraft.
Kenneth Campbell, Wright Aeronautical Corporation.
Opie Chenoweth, Army Air Corps, Matériel Division, Wright Field.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
A. J. Larrecq, Allison Engineering Company.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Oscar W. Schey, National Advisory Committee for Aeronautics.
Chester Smith, General Electric Co.
Lt. Comdr. S. B. Spangler, United States Navy.

SPECIAL SUBCOMMITTEE ON EXHAUST GAS TURBINES AND INTERCOOLERS

Opie Chenoweth, Matériel Division, Army Air Corps, Wright Field, Chairman.
A. L. Berger, Matériel Division, Army Air Corps, Wright Field.
Rudolph Birmann, Turbo Engineering Corporation.
K. A. Browne, Wright Aeronautical Corporation.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
John G. Lee, United Aircraft Corporation.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Charles Morris, General Electric Co.
Lt. C. J. Pfingstag, United States Navy.
Benjamin Pinkel, National Advisory Committee for Aeronautics.
S. R. Puffer, General Electric Co.

SPECIAL SUBCOMMITTEE ON INDUCTION-SYSTEM DE-ICING

William C. Lawrence, American Airlines, Inc., Chairman.
Dr. H. C. Dickinson, National Bureau of Standards.
Lt. Henry R. Dozier, United States Navy.
Robert E. Johnson, Wright Aeronautical Corporation.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Milton J. Kittler, Holley Carburetor Co.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Irving R. Metcalf, Civil Aeronautics Administration.
Frank C. Mock, Stromberg Carburetor Division, Bendix Aviation Corporation.
Gaylord W. Newton, Civil Aeronautics Administration.
Victor Skoglund, Pratt & Whitney Aircraft.
Maj. D. W. Watkins, Air Corps, United States Army.
A. W. Young, National Advisory Committee for Aeronautics.

COMMITTEE ON AIRCRAFT MATERIALS

Dr. Lyman J. Briggs, Chairman.
Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.
S. K. Colby, Aluminum Co. of America.

Edgar H. Dix, Jr., American Magnesium Corporation.
John Easton, Civil Aeronautics Administration.
Warren E. Emley, National Bureau of Standards.
Captain Garland Fulton, United States Navy.
Jack T. Gray, Civil Aeronautics Administration.
Charles H. Helms, National Advisory Committee for Aeronautics.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Maj. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
H. S. Rawdon, National Bureau of Standards.
John W. Sands, International Nickel Co.
E. C. Smith, Republic Steel Corporation.
Lieutenant Commander James E. Sullivan, United States Naval Reserve.
Paul F. Voigt, Jr., Carnegie-Illinois Steel Corporation.
Dr. Edward Warner.

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

H. S. Rawdon, National Bureau of Standards, Chairman.
Allen W. Dallas, Civil Aeronautics Administration.
E. H. Dix, Jr., American Magnesium Corporation.
Capt. Garland Fulton, United States Navy.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
E. C. Smith, Republic Steel Corporation.
Paul F. Voigt, Jr., Carnegie-Illinois Steel Corporation.
Prof. H. L. Whittemore, National Bureau of Standards.
A. W. Winston, Dow Chemical Co.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

Warren E. Emley, National Bureau of Standards, Chairman.
Charles J. Cleary, Matériel Division, Army Air Corps, Wright Field.
Allen W. Dallas, Civil Aeronautics Administration.
Charles H. Helms, National Advisory Committee for Aeronautics.
E. F. Hickson, National Bureau of Standards.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Lt. Comdr. James E. Sullivan, United States Naval Reserve.
George W. Trayer, Forest Service, Department of Agriculture.

COMMITTEE ON AIRCRAFT STRUCTURES

Dr. Lyman J. Briggs, Chairman.
John Easton, Civil Aeronautics Administration.
Lt. Comdr. Robert S. Hatcher, United States Navy.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Maj. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Capt. Charles K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. Walter Ramberg, National Bureau of Standards.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Lt. Albert B. Scoles, United States Navy.
Edward I. Ryder, Civil Aeronautics Administration.
Dr. L. B. Tuckerman, National Bureau of Standards.
Dr. Edward Warner.

SPECIAL SUBCOMMITTEE TO MAKE SURVEY OF TECHNIQUE AND EQUIPMENT FOR ELASTIC EXAMINATION OF LARGE AIRCRAFT STRUCTURES IN LIEU OF DESTRUCTION TESTS

Richard V. Rhode, National Advisory Committee for Aeronautics, Chairman.
Lt. Comdr. Robert S. Hatcher, United States Navy.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Maj. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Irving R. Metcalf, Civil Aeronautics Administration.
Lt. Albert B. Scoles, United States Navy.
R. L. Templin, Aluminum Co. of America.
Dr. L. B. Tuckerman, National Bureau of Standards.

SPECIAL SUBCOMMITTEE TO DIRECT RESEARCH IN APPLIED STRUCTURES

Lt. Comdr. Robert S. Hatcher, United States Navy, Chairman.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
Maj. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Edward I. Ryder, Civil Aeronautics Administration.
Dr. L. B. Tuckerman, National Bureau of Standards.

COMMITTEE ON AIRCRAFT ACCIDENTS

Dr. Edward Warner, Chairman.
Lt. Comdr. William A. Evans, Jr., United States Navy.
Maj. Barney M. Giles, Air Corps, United States Army.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex-officio member).
J. W. Lankford, Civil Aeronautics Board.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex-officio member).
Commander A. E. Montgomery, United States Navy.
Maj. Charles W. Sullivan, Air Corps, United States Army.
Grove Webster, Civil Aeronautics Administration.

COMMITTEE ON AERONAUTICAL INVENTIONS AND DESIGNS

Dr. Lyman J. Briggs, Chairman.
Maj. Gen. George H. Brett, Air Corps, United States Army.
Dr. Jerome C. Hunsaker.
Capt. Sydney M. Kraus, United States Navy.
John F. Victory, Secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Vannevar Bush, Chairman.
Dr. Charles G. Abbot.
Dr. George J. Mead.
John F. Victory, Secretary.

SPECIAL COMMITTEE ON SITE FOR AIRCRAFT ENGINE-RESEARCH LABORATORY

During the past year, a Special Committee on Site, with the following membership, was appointed to determine the location best suited to the needs of the proposed new aircraft engine-research laboratory:

Dr. Vannevar Bush, Chairman.
Maj. Gen. George H. Brett, Air Corps, United States Army.
Dr. Lyman J. Briggs.
Capt. Sydney M. Kraus, United States Navy.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detailed problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft. No aircraft circulars were issued during the past year.

Because of the present national emergency, and at the request of the Army and the Navy, the technical reports and technical notes of the Committee were on June 1, 1940, placed in a restricted status, and as such are not available for general distribution.

The following are lists of the publications released during the past year:

TECHNICAL REPORTS

No.

681. The Unsteady Lift of a Wing of Finite Aspect Ratio. By Robert T. Jones.
682. Flame Speeds and Energy Considerations for Explosions in a Spherical Bomb. By Ernest F. Fiock, Charles F. Marvin, Jr., Frank R. Caldwell, and Carl H. Roeder.
686. Stability of Castering Wheels for Aircraft Landing Gears. By Arthur Kantrowitz.

TECHNICAL NOTES

731. Tests in the Gust Tunnel of a Model of the XBM–1 Airplane. By Philip Donely and C. C. Shufflebarger.
732. A Simple Method of Obtaining Span Load Distributions. By Albert Sherman.
733. Experimental Study of Torsional Column Failure. By Alfred S. Niles.
734. Pressure-Distribution Investigation of an N. A. C. A. 0009 Airfoil with a 50-Percent-Chord Plain Flap and Three Tabs. By William G. Street and Milton B. Ames, Jr.
735. Pressure-Distribution Measurements on a Tapered Wing with a Partial-Span Split Flap in Curved Flight. By Th. Troller and F. Rokus.
736. Tidewater and Weather-Exposure Tests on Metals Used in Aircraft. By Willard Mutchler and W. G. Galvin.
737. Photoelastic Analysis of Three-Dimensional Stress Systems Using Scattered Light. By R. Weller and J. K. Bussey.
738. Corrugated Metal Diaphragms for Aircraft Pressure-Measuring Instruments. By W. A. Wildhack and V. H. Goerke.
739. A Recurrence Formula for Shear-Lag Problems. By Paul Kuhn.
740. Stress Concentration Around an Open Circular Hole in a Plate Subjected to Bending Normal to the Plane of the Plate. By C. Dumont.
741. Observations in Flight of the Region of Stalled Flow over the Blades of an Autogiro Rotor. By F. J. Bailey, Jr., and F. B. Gustafson.
742. Pressure-Distribution Measurements on a Rectangular Wing with a Partial-Span Split Flap in Curved Flight. By Frank G. Rokus.
743. Local Instability of Columns with I-, Z-, Channel, and Rectangular-Tube Sections. By Elbridge Z. Stowell and Eugene E. Lundquist.
744. The Development of Electrical Strain Gages. By A. V. de Forest and H. Leaderman.
745. Tests of a Gust-Alleviating Flap in the Gust Tunnel. By Philip Donely and C. C. Shufflebarger.
746. The Frequencies of Cantilever Wings in Beam and Torsional Vibrations. By C. P. Burgess.
747. Propeller Rotation Noise Due to Torque and Thrust. By Arthur F. Deming.
748. Principles, Practice, and Progress of Noise Reduction in Airplanes. By Albert London.
749. A New Method of Studying the Flow of the Water Along the Bottom of a Model of a Flying-Boat Hull. By Kenneth E. Ward.
750. A Generalized Vortex Theory of the Screw Propeller and Its Application. By Hans Reissner.
751. Damping Formulas and Experimental Values of Damping in Flutter Models. By Robert P. Coleman.
752. An Investigation of Sheet-Stiffener Panels Subjected to Compression Loads with Particular Reference to Torsionally Weak Stiffeners. By Louis G. Dunn.
753. Measurement of the Forces Acting on Gliders in Towed Flight. By W. B. Klemperer.
754. An Investigation of the Prevention of Ice on the Airplane Windshield. By Lewis A. Rodert.
755. Wind-Tunnel Investigation of an N. A. C. A. 23030 Airfoil with Various Arrangements of Slotted Flaps. By I. G. Recant.
756. The Effect of Piston-Head Shape, Cylinder-Head Shape, and Exhaust Restriction, on the Performance of a Piston-Ported Two-Stroke Cylinder. By A. R. Rogowski, C. L. Bouchard, and C. Fayette Taylor.
757. A Study of Unsymmetrical-Loading Conditions. By Henry A. Pearson.
758. Measurements and Analysis of the Motion of a Canard Airplane Model in Gusts. By Philip Donely, Harold B. Pierce, and Philip W. Pepoon.
759. Pressure-Distribution Investigation of a N. A. C. A. 0009 Airfoil with a 30-Percent-Chord Plain Flap and Three Tabs. By Milton B. Ames, Jr., and Richard I. Sears.

760. A Full-Scale Investigation of the Effect of Several Factors on the Shimmy of Castering Wheels. By Walter B. Howard, Jr.

761. Pressure-Distribution Investigation of an N. A. C. A. 0009 Airfoil with an 80-Percent-Chord Plain Flap and Three Tabs. By Milton B. Ames, Jr., and Richard I. Sears.

762. The Flow of a Compressible Fluid Past a Sphere. By Carl Kaplan.

763. Wind-Tunnel Investigation of Two Airfoils with 25-Percent-Chord Gwinn and Plain Flaps. By Milton B. Ames, Jr.

TECHNICAL MEMORANDUMS

912. Increase of the Specific Load Under Tension, Compression, and Buckling of Welded Steel Tubes in Airplane Construction by Suitable Treatment of Structural Steel and by Proper Design. By J. Müller. From Luftfahrtforschung, Vol. 16, No. 1, January 10, 1939.

913. Measurement of the True Dynamic and Static Pressures in Flight. By Georg Kiel. From Luftfahrtforschung, Vol. 15, No. 12, December 10, 1938.

914. Engine Knock and Combustion Chamber Form. By Karl Zinner. From Automobiltechnische Zeitschrift, Vol. 42, No. 9, May 15, 1939.

915. Experimental and Analytical Investigation of a Monocoque Wing Model Loaded in Bending. By E. Schapitz, H. Feller, and H. Köller. From Luftfahrtforschung, Vol. 15, No. 12, December 10, 1938.

916. Activation of Hydrocarbons and the Octane Number. By Marcel Peschard. From Publications Scientifiques et Techniques du Ministere de l'Air, No. 132, 1938.

917. The Effect of Compressibility on the Pressure Reading of a Prandtl Pitot Tube at Subsonic Flow Velocity. By O. Walchner. From Deutche Luftfahrtforschung Jahrbuch, 1938.

918. The Enlarged N. A. C. A. Tank, and Some of Its Work. By Starr Truscott. From supplementary volume to Jahrbuch 1938 der deutschen Luftfahrtforschung. (Containing papers presented at Lilienthal Gesellschaft für Luftfahrtforschung, Oct. 1938.)

919. Report on Ice Formation on Aircraft. By the French Committee for the Study of Ice Formation, May 19, 1938. From Bulletin des Services Techniques No. 85, Publications Scientifiques et Techniques du Ministere de l'Air.

920. The Effect of the Slipstream on an Airplane Wing. By A. Franke and F. Weinig. From Luftfahrtforschung, Vol. 15, No. 6, June 6, 1938.

921. Contribution to the Aerodynamics of Rotating-Wing Aircraft. By G. Sissingh. From Luftfahrtforschung, Vol. 15, No. 6, June 6, 1938.

922. The Breda Wind Tunnel. By Mario Pittoni. From Auto Moto Avio, No. 5, March 1939.

923. Measurement of the Air-Flow Velocity in the Cylinder of an Airplane Engine. By Hermann Wenger. From Luftfahrtforschung, Vol. 16, No. 2, February 20, 1939.

924. Modern Methods of Fuel Testing. By F. Seeber. From Luftfahrtforschung, Vol. 16, No. 8, August 20, 1939.

925. Effect of Wing Loading, Aspect Ratio, and Span Loading on Flight Performances. By B. Göthert. From Luftfahrtforschung, Vol. 16, No. 5, May 20, 1939.

926. DFS Dive-Control Brakes for Gliders and Airplanes. By Hans Jacobs and Adolf Wanner; and Analytical Study of the Drag of the DFS Dive-Control Brake. By Adolf Wanner. From Jahrbuch 1938 der deutschen Luftfahrtforschung; Luftwissen, Vol. 4, No. 7, July 1937; and Luftwissen, Vol. 6, No. 5, May 1939.

927. Constant-Pressure Blowers. By E. Sörensen. From Zeitschrift des Vereines deutscher Ingenieure, Vol. 83, No. 32, August 12, 1939.

928. Knocking in an Internal-Combustion Engine. By A. Sokolik and A. Volnov. From Technical Physics of the U. S. S. R., Vol. 3, No. 9, 1936.

929. Aerodynamics of Rotating-Wing Aircraft with Blade-Pitch Control. By A. Pflüger. From Luftfahrtforschung, Vol. 16, No. 7, July 20, 1939.

930. Experimental Contribution to the Study of Combustion in Compression-Ignition Engines. By R. Duchene. From Publications Scientifiques et Techniques du Ministere de l'Air, No. 149, 1939.

931. Testing of High-Octane Fuels in the Single-Cylinder Airplane Engine. By Fritz Seeber. From Luftfahrtforschung, Vol. 16, No. 1, January 10, 1939.

932. Theoretical and Experimental Investigations of the Drag of Installed Aircraft Radiators. By W. Barth. From Proceedings of the Fifth International Congress for Applied Mechanics, Cambridge, Mass., September 12–16, 1938.

933. The Strength of Shell and Tubular Spar Wings. By H. Ebner. From Luftfahrtforschung, Vol. 14, Nos. 4 and 5, April 20, 1937.

934. Application of the Methods of Gas Dynamics to Water Flows with Free Surface. Part I. Flows with No Energy Dissipation. By Ernst Preiswerk. From Institut für Aerodynamik, Eidgenössiche Technische Hochschule, Zurich, No. 7, 1938.

935. Application of the Methods of Gas Dynamics to Water Flows with Free Surface. Part II. Flows with Momentum Discontinuities (Hydraulic Jumps). By Ernst Preiswerk. From Institut für Aerodynamik, Eidgenössiche Technische Hochschule, Zurich, No. 7, 1938.

936. Measurement of Knock Characteristics in Spark-Ignition Engines. By R. Schütz. From Automobiltechnische Zeitschrift, Vol. 42, No. 13, July 10, 1939.

937. Stresses in Single-Spar Wing Constructions with Incompletely Built-Up Ribs. By F. Reinitzhuber. From Luftfahrtforschung, Vol. 16, No. 7, July 20, 1939.

938. The Shock-Absorbing System of the Airplane Landing Gear. By Pietro Callerio. From L'Aerotecnica, Vol. 19, No. 6, June 1939.

939. The Torsion of Box Beams with One Side Lacking. By E. Cambilargiu. From Luftfahrtforschung, Vol. 16, No. 8, August 20, 1939.

940. The Lead Susceptibility of Fuels and Its Dependence on the Chemical Composition. By O. Widmaier. From Automobiltechnische Zeitschrift, Vol. 43, No. 3, February 10, 1940.

941. Some Data on the Static Longitudinal Stability and Control of Airplanes (Design of Control Surfaces). By A. Martinov and E. Kolosov. From Central Aero-Hydrodynamical Institute, Moscow, 1936. Report No. 278.

942. On the Theory of Unsteady Planing and the Motion of a Wing with Vortex Separation. By L. Sedov. From Central Aero-Hydrodynamical Institute, Moscow, 1936. Report No. 252.

943. Tests of Lead-Bronze Bearings in the DVL Bearing-Testing Machine. By G. Fischer. From Luftfahrtforschung, Vol. 16, No 7, July 20, 1939.

944. Italian High-Speed Airplane Engines. By C. F. Bona. (Paper presented at Volta meeting in Italy, Sept. 30, to Oct. 6, 1935.)

945. Experiments on Ball and Roller Bearings under Conditions of High Speed and Small Oil Supply. By Günter Getzlaff. From Jahrbuch 1938 der deutschen Luftfahrtforschung.

946. Experimental Results with Airfoils Tested in the High-Speed Tunnel at Guidonia. By Antonio Ferri. From Atti di Guidonia, No. 17, September 20, 1939.
947. New Equipment for Testing the Fatique Strength of Riveted and Welded Joints. By W. Müller. From special reprint of Schweizer Archiv, No. 10, 1937.
948. A Simple Approximation Method for Obtaining the Spanwise Lift Distribution. By O. Schrenk. From Luftwissen, Vol. 7, No. 4, April 1940.
949. The Maximum Delivery Pressure of Single-Stage Radial Superchargers for Aircraft Engines. By W. von der Null. From Luftwissen, Vol. 7, No. 5, May 1940.
950. Buckling Tests with a Spar-Rib Grill. By Josef Weinhold. From Luftfahrtforschung, Vol. 17, No. 3, March 20, 1940.
951. Variation in Velocity Profile with Change in Surface Roughness of Boundary. By W. Jacobs. From Zeitschrift für angewandte Mathematik und Mechanik, Vol. 19, No. 2, April 1939.
952. Standards for Discharge Measurement with Standardized Nozzles and Orifices. German Industrial Standard 1952. Fourth edition. From VDI–Verlag G. m. b. H., Berlin, 1937.
953. Pressure and Temperature Measurement in Supercharger Investigations. By A. Franz. From Jahrbuch 1938 der deutschen Luftfahrtforschung.
954. Limits of Single-Stage Compression in Centrifugal Superchargers for Aircraft. By K. Kollmann. From Luftwissen, Vol. 7, No. 3, March 1940.

FINANCIAL REPORT

APPROPRIATIONS FOR FISCAL YEAR 1940

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1940, as contained in the Independent Offices Appropriation Act approved March 16, 1939, was $1,717,000. A supplemental appropriation of $223,980 was made available in the Second Deficiency Appropriation Act, fiscal year 1939, approved May 2, 1939, for the same purposes specified in the Committee's regular appropriation act for 1939, to continue available until June 30, 1940. The amount expended during fiscal year 1939 from this fund was $29,434, leaving a balance of $194,546 available for expenditure during fiscal year 1940. An additional amount of $109,020 was made available in the Third Deficiency Appropriation Act, fiscal year 1939, approved August 9, 1939, for the same purposes specified in the Committee's regular appropriation act for 1940. The total amount available for general purposes during the fiscal year 1940, therefore, was $2,020,566. The amount expended during 1940 was $2,020,557, itemized as follows:

Personal services	$1,388,881
Supplies and materials	134,184
Communication service	4,999
Travel expenses	19,925
Transportation of things	3,463
Furnishing of electricity	54,001
Repairs and alterations	22,730
Special and miscellaneous investigations	70,000
Contracts for research	25,000
Equipment	$297,374
Expended and obligated	2,020,557
Unexpended balance	9
Total, general appropriation	2,020,566

The appropriation for printing and binding for 1940 was $23,000, of which $22,991 was expended.

The Independent Offices Appropriation Act approved March 16, 1939, also provided $340,000 for the completion at Langley Field of the two-dimensional wind tunnel for which an initial appropriation of $200,000 was provided in the 1939 act, and $100,000 for modernization of the free-spinning tunnel. The total amount, $440,000, was obligated during the fiscal year 1940 for the purposes specified.

The Second Deficiency Appropriation Act approved May 2, 1939, also provided $2,140,000 for the construction and equipment of additional facilities at Langley Field, Va., including connections to public utilities, and rights-of-way for, and installation of power lines, this amount to remain available until expended. No obligations were placed under this fund during the fiscal year 1939. During the fiscal year 1940, the amount of $1,776,053 was obligated under this fund.

The Third Deficiency Appropriation Act approved August 9, 1939, also provided $1,890,980 for beginning construction of an additional research laboratory and authorized the Committee to enter into contracts for construction and equipment, including the purchase of land, not to exceed a total of $10,000,000. Moffett Field, Calif., was selected as the site of this additional laboratory, which is known as the Ames Aeronautical Laboratory, and the amount of $2,601,156 was obligated during 1940 for construction and equipment.

The amount of $37,089 was received during the fiscal year 1940 and credited to eleven special deposit accounts to cover the cost of scientific investigations for aircraft manufacturers. Nine investigations were completed during 1940, resulting in the deposit in the Treasury of $23,466 to the credit of miscellaneous receipts, as proceeds, and the return of unexpended balances totaling $3,724 to depositors.

An allotment of $250 was received from the State Department for payments during the fiscal year 1940 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies. Of this amount $145 was paid during the fiscal year 1940 to employees of the Committee stationed in the Paris office, leaving a balance of $105 which was turned back into the Treasury.

APPROPRIATIONS FOR FISCAL YEAR 1941

The general appropriation for the fiscal year 1941, as contained in the Independent Offices Appropriation

Act approved April 18, 1940, was $2,775,000, and the amount provided for printing and binding was $25,000. This act also provided $1,000,000 for construction and equipment of additional facilities at Langley Field, Va., and $4,200,000 for continuing construction and equipment of the new Ames Aeronautical Laboratory at Moffett Field, Calif. The total amount provided for the Committee in this act therefore was $8,000,000.

The First Supplemental National Defense Appropriation Act, 1941, approved June 26, 1940, provided $2,000,000 for construction and equipment of an airplane engine-research laboratory, including acquisition of land at a site to be selected by the Committee, rights-of-way, and connections to public utilities, installation of power lines, etc., and authorized entering into contracts not to exceed a total cost of $8,400,000. This act also provided $1,200,000 for construction and equipment of a generating power plant at Langley Field, Va. No obligations were placed under these funds during the fiscal year 1940.

CONCLUSION

Scientific research is the most fundamental activity of the Government in connection with the development of America's potential strength in the air. No matter how greatly production facilities may be increased, no matter how many pilots may be trained, unless the aircraft that are built for action are at least equal in performance to those of any possible enemy, the whole effort will be largely wasted.

It is the responsibility of the National Advisory Committee for Aeronautics to anticipate the research needs of aviation, and the progress that can be made, and to provide the Army, the Navy, and the industry in the United States with a constant flow of the new knowledge that is essential to American leadership in aircraft performance.

With the continued farsighted support of the President and of the Congress, the Committee's research facilities, as yet concentrated chiefly at Langley Field, Va., are being greatly strengthened by the construction of the Ames Aeronautical Laboratory for aerodynamic research at Moffett Field, Calif., and of an aircraft engine-research laboratory at Cleveland, Ohio. The former is still largely in the construction stage, and the building of the latter has hardly begun. As these additional facilities are urgently needed, construction is being pushed with all possible vigor. When these facilities come into full operation, the country will have much better assurance that America will be able to keep in advance of the technical developments in aeronautics in other countries.

In the scientific study of the problems of flight, the talent of America has been marshalled through the technical subcommittees and through the stimulation and coordination of research in scientific and educational institutions. Progress in military and naval aviation will find reflection in improved performance, efficiency, and safety of civil and commercial aviation. The Committee believes that commercial aviation will prove of ever-increasing importance to the United States in promoting international trade and good will, especially in the Western Hemisphere. When the present wars have ended, aviation will have an opportunity to prove its real value to civilization in shortening the distances between nations and in facilitating international trade and commerce. When that day comes, the extension of world trade routes of the air will bring some compensation for the awful destruction wrought and to be wrought by military aviation before peace again prevails.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS,
VANNEVAR BUSH, *Chairman.*

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of the

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1941

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TWENTY-SEVENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1941

ADMINISTRATIVE REPORT
WITHOUT TECHNICAL REPORTS

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LETTER OF TRANSMITTAL

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Twenty-seventh Annual Report of the Committee covering the fiscal year ended June 30, 1941.

Franklin D. Roosevelt.

The White House,
January 12, 1942.

LETTER OF SUBMITTAL

National Advisory Committee for Aeronautics,
Washington, D. C., December 15, 1941.

Mr. President:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C. title 50, sec. 153) I have the honor to submit herewith the Twenty-seventh Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1941.

The past year was one of great progress in aeronautics. Aircraft speed, range, capacity, altitude, fire power and other military characteristics were improved. Scientific research was the foundation for the advances made. Research facilities were notably increased by expansion at Langley Field, Va., and by bringing into operation, as constructed, various units of the new Ames Aeronautical Laboratory at Moffett Field, Calif. The engine research laboratory recently authorized is under construction at Cleveland, Ohio.

Vigorous research gives the only assurance that our construction program will yield aircraft unexcelled by those of any other nation. In this report the Committee describes its research organization and methods but, in the public interest, withholds the publication of details.

Respectfully submitted.

Jerome C. Hunsaker, *Chairman.*

The President,
The White House, Washington, D. C.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, 1500 NEW HAMPSHIRE AVENUE NW., WASHINGTON, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

JEROME C. HUNSAKER, Sc. D., *Chairman*,
Cambridge, Mass.

GEORGE J. MEAD, Sc. D., *Vice Chairman*,
Washington, D. C.

CHARLES G. ABBOT, Sc. D.,
Secretary, Smithsonian Institution.

HENRY H. ARNOLD, Lieut. General, United States Army,
Deputy Chief of Staff for Air, Chief of the Air Forces,
War Department.

GEORGE H. BRETT, Major General, United States Army,
Chief of the Air Corps, War Department.

LYMAN J. BRIGGS, Ph. D.,
Director, National Bureau of Standards.

VANNEVAR BUSH, Sc. D.,
Washington, D. C.

DONALD H. CONNOLLY, B. S.,
Administrator of Civil Aeronautics.

WILLIAM F. DURAND, Ph. D.
Stanford University, Calif.

ROBERT H. HINCKLEY, A. B.,
Assistant Secretary of Commerce.

SYDNEY M. KRAUS, Captain, United States Navy.
Bureau of Aeronautics, Navy Department.

FRANCIS W. REICHELDERFER, Sc. D.,
Chief, United States Weather Bureau.

JOHN H. TOWERS, Rear Admiral, United States Navy.
Chief, Bureau of Aeronautics, Navy Department.

EDWARD WARNER, Sc. D.,
Washington, D. C.

ORVILLE WRIGHT, Sc. D.,
Dayton, Ohio.

GEORGE W. LEWIS, *Director of Aeronautical Research* S. PAUL JOHNSTON, *Coordinator of Research*

JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer-in-Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

SMITH J. DEFRANCE, *Engineer-in-Charge, Ames Aeronautical Laboratory Moffett Field, Calif.*

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS

AIRCRAFT STRUCTURES
AIRCRAFT ACCIDENTS
INVENTIONS AND DESIGNS

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

LANGLEY MEMORIAL AERONAUTICAL LABORATORY
LANGLEY FIELD, VA.

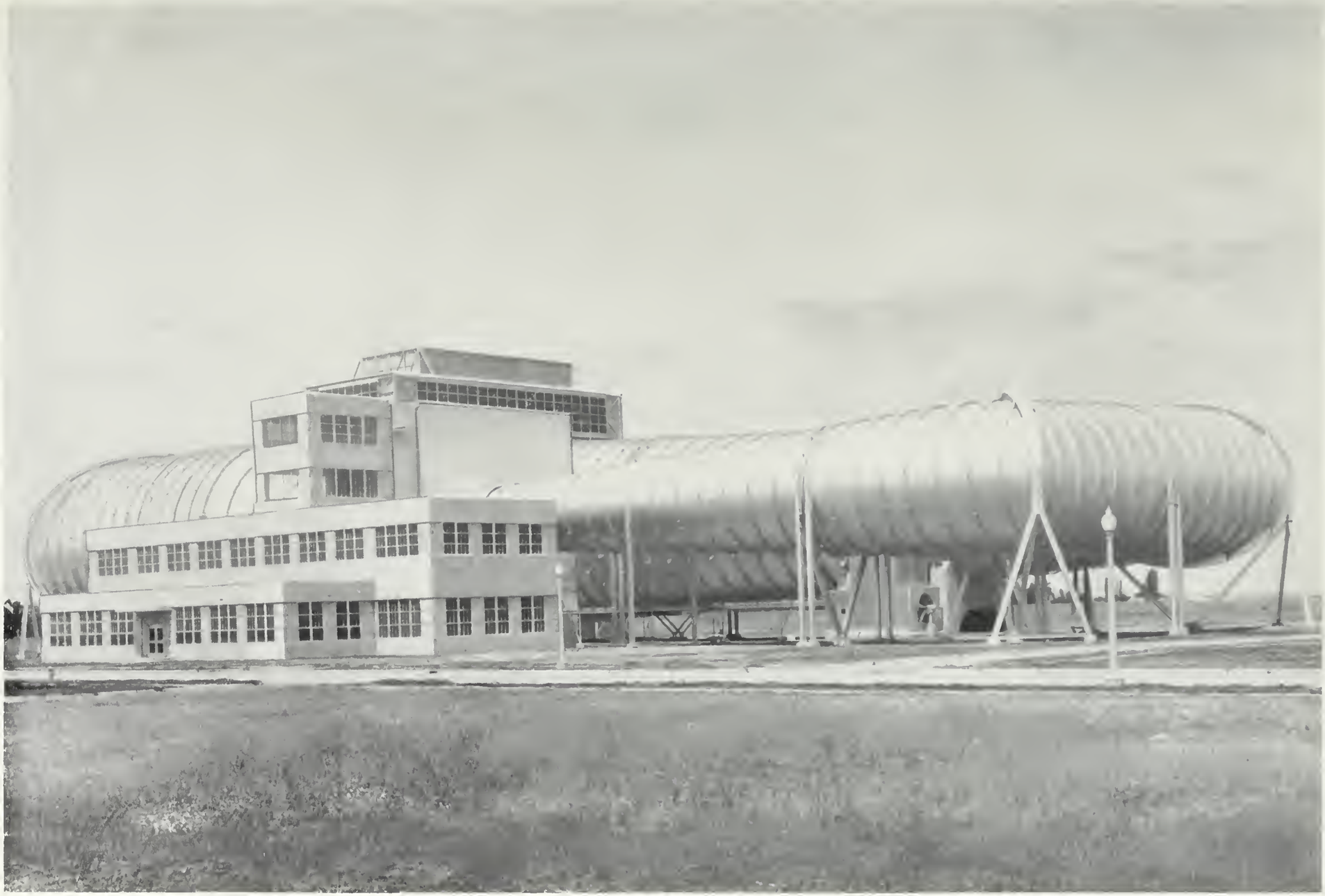
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIF.

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

OFFICE OF AERONAUTICAL INTELLIGENCE

WASHINGTON, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics



New 16-foot high-speed wind tunnel, Ames Aeronautical Laboratory, Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

First Meeting in New Headquarters, 1500 New Hampshire Avenue, Dupont Circle, Washington, D. C.

October 23, 1941.

Left to right, seated: Dr. William F. Durand; Dr. F. W. Reichelderfer, Chief, United States Weather Bureau; Brig. Gen. Donald H. Connolly, Civil Aeronautics Administrator; Dr. Vannevar Bush; Rear Admiral John H. Towers, Chief, Bureau of Aeronautics, Navy Department; Dr. Orville Wright; Dr. Jerome C. Hunsaker, Chairman; Dr. George J. Mead, Vice Chairman; Dr. Charles G. Abbot, Secretary, Smithsonian Institution; Dr. Edward Warner; Dr. L. J. Briggs, Director, National Bureau of Standards; Capt. Sydney M. Kraus, Bureau of Aeronautics, Navy Department. Standing: S. Paul Johnston, Coordinator of Research; Dr. George W. Lewis, Director of Aeronautical Research; John F. Victory, Secretary.

TWENTY-SEVENTH ANNUAL REPORT
OF THE
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 26, 1941.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151), which established the National Advisory Committee for Aeronautics, the Committee submits herewith its Twenty-seventh Annual Report for the fiscal year 1941.

Against a background of fallen nations the airplane looms as the instrumentality that has changed previous concepts of military power and the course of history. In the emergency created by this situation, the United States is expending unprecedented sums for the production of aircraft, on the effectiveness of which the security of the Nation may largely depend.

Vast quantities of aircraft alone seem insufficient unless their performance is at least equal to those they may be called upon to oppose. This makes it essential to choose the most advanced designs for production, but allows little time to prove the new features incorporated. It falls to the aeronautical laboratories not only to provide the new ideas necessary to insure superior performance, but at the same time to prove in advance the soundness of the design as a whole. The Committee's work, therefore, falls into two principal categories: namely, research to furnish new ideas; and development, or the application of these ideas to current military designs. The present emergency has naturally revised the priorities in connection with the long-range research program, to the end that those things which give most immediate promise are emphasized. It has been possible, due to close collaboration with the Army, Navy, and aircraft industry, to incorporate the results of a great deal of the Committee's work in current production aircraft, thus making them more effective military weapons.

Only continued scientific research can give the Nation assurance that its aircraft will be kept at least the equal of those of any other nation. In order to develop aircraft to their full potentialities, both in peace and in war, scientific research must be prosecuted with vigor and imagination.

Survey of research needs.—As the threat of war grew grave, in 1938, and the pace of armament accelerated, the Committee surveyed its research needs in anticipation of greatly increased responsibilities. The Committee restudied the research facilities which would be needed to work effectively upon a great variety of problems of the airplane, its power plant, and its equipment; and proposed a program for the construction of additional and improved wind tunnels to investigate large airplane models at speeds in excess of current military requirements and for greatly increased facilities for power-plant research.

The Congress provided funds, first, to increase the research facilities at Langley Field, Va., and to provide an electric generating plant to permit operation of wind tunnels at all hours of the day; second, to establish a new aerodynamic research station, now known as the Ames Aeronautical Laboratory, at Moffett Field, Calif.; and third, to establish a separate station for fundamental research on aircraft engine problems. This station is now under construction at Cleveland, Ohio.

The Committee placed in operation during the past year at the Langley and Ames laboratories new wind tunnels, representing an expansion of more than 100 percent in the wind tunnels devoted to urgent defense problems, and is proceeding with construction of other wind tunnels, representing another 100 percent increase over those available a year ago. The regular and supplemental appropriations for the Committee for the fiscal year 1942 provide also for a substantial increase in personnel.

The Committee's ability to meet its growing responsibilities has thus been materially aided through the provision of a more adequate staff and better research facilities. At the same time it has had the effective support and cooperation of representatives of the Government agencies concerned with aeronautics and of a large number of experts from the industry and from private life. These experts have served on technical subcommittees charged with the planning of detailed research projects. Further reference will be made to the Committee's policy in securing such assistance.

Problems affecting the character and scope of aeronautical research.—The desired characteristics of the naval and military types of aircraft now included in the national defense program are such that both fundamental and specialized research are necessary to realize the performance required.

The outstanding fighters of 1940–41—the British Spitfire and Hurricane airplanes and the German Messerschmitt 109F—had maximum speeds of the order of 360 miles per hour. The American aircraft program must provide new fighters for 1941–42 of much higher speed. A speed of 400 miles per hour and as much more as is practicable is an obvious necessity. The factors involved include not only clean aerodynamic design, but the discovery of new principles and facts whose application in design leads to real improvements. It is not enough merely to increase the horsepower and to smooth the surfaces.

It was necessary to develop a new wing section of low-drag type, to obtain accurate data in a low-turbulence wind tunnel of its lift and drag, to determine the effect of various types of flaps for increasing lift, and the action of normal and other lateral control devices. It was also essential to reexamine the method of cowling and cooling both air-cooled and liquid-cooled engines at high air speeds. Special cowlings were required to handle the air needed to cool the engine, the oil radiator, the intercooler and, in the liquid-cooled type, the radiator. This work was based on theoretical analysis and proved in wind-tunnel and flight tests.

Propellers of usual design are inefficient at extreme speeds. New propeller blade sections and new plan forms for the blade have had to be developed to keep the losses under those conditions to a minimum. Again theoretical studies and wind-tunnel tests together were necessary to arrive at a practical solution.

At high speed the airplane is subject to compressibility effects. The wing, the fuselage, the propeller, and other parts must be designed to eliminate compression waves as far as possible. This requires testing in a high-speed wind tunnel.

Altitude requirements have been much increased. They demand better supercharging equipment and better cooling of the engine and the intercooler at high altitudes.

In planning the design of a new military airplane special model tests are necessary to determine its spinning characteristics. Where the design is of a radically new form tests are also made in the free-flight tunnel to be assured that the design will have adequate stability and control.

Research facilities.—The Committee initiated its present program of expansion of research facilities in 1938. Through the support of the President and the Congress since that time, the Committee has been able to place in operation during the past year seven wind tunnels of major significance, and a structures research laboratory, all now fully engaged on urgent problems relating to the defense program. The new wind tunnels at Langley Field are: A 20-foot free-spinning tunnel; a stability tunnel; a 2-dimensional tunnel; and a 16-foot high-speed tunnel. At Moffett Field the new tunnels so far placed in operation include a 16-foot high-speed tunnel, and two 7- by 10-foot high-speed tunnels.

There are under way at Moffett Field a low-turbulence high-speed tunnel, a supersonic tunnel, and a full-scale tunnel.

An aircraft engine research laboratory is under construction at Cleveland, Ohio. This will include: special equipment for research on engines and accessories, propellers, fuels, and lubricants; an ice tunnel for the study of problems of ice formation in flight; and a novel, high-speed engine-research wind tunnel to operate under conditions of temperature and density existing at high altitudes.

There is also under construction at Langley Field a second seaplane towing tank, a seaplane impact basin, an electric power-generating plant, an additional shop building, and extensions to the Flight Research Laboratory and to the service and administration buildings.

In the present emergency the Committee, with the special approval of the Congress, has increased its use of available research facilities in educational and scientific institutions and in the National Bureau of Standards. The work so done supplements that of the Committee's own laboratories; and the Committee's research contracts enable scientists of special qualifications to work upon problems of national importance which they would otherwise lack the means to investigate.

Relation of research to civil aviation.—With the exception of dive-bombing problems and problems incident to armament installations, practically all of the research of the Committee is directly applicable to civil types of aircraft. Improvements in large two- and four-engine airplanes of the bombing type will undoubtedly be reflected in transport airplanes of tomorrow. New and improved engine installations, wing forms, and propeller designs developed for military types will be important factors in increasing the speed and efficiency of future civil aircraft.

Strengthening of subcommittees.—Under the law it is the duty of the National Advisory Committee for Aeronautics to "supervise and direct the scientific study of the problems of flight with a view to their practical solution" and also to "direct and conduct research and experiment in aeronautics."

To assist in the discharge of these duties and in the determination of present and future research needs of aeronautics, civil and military, the Committee has established standing technical subcommittees composed of specially qualified representatives of the governmental agencies concerned and of experts from private life. The members of the subcommittees, like the members of the main Committee, serve as such without compensation.

The subcommittees prepare and recommend research projects. Most of the projects recommended for investigation are assigned to the Committee's laboratories. Some projects are assigned to the National Bureau of Standards and others to universities and technical schools, depending on where the necessary research equipment exists and upon the availability of a qualified staff. This policy makes effective use of existing research facilities, stimulates aeronautical research, and also has the advantage of training research personnel.

The technical subcommittees, now increased in number and strengthened in personnel, have been meeting with greater frequency. This has led to stimulation and clarification of thinking and to greater coordination of effort. In all some 183 persons are serving on the various technical subcommittees.

In addition, frequent conferences devoted to special topics are held with engineers and designers from the industry who are responsible for parts of the defense program. These conferences bring members of the Committee's scientific staff in contact with those who apply the results of their research work.

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PART I

TECHNICAL COMMITTEES

In order better to meet its responsibilities, the National Advisory Committee for Aeronautics has established a group of technical committees to recommend to the main Committee programs of research to be conducted in their respective fields. As a result of the nature of their organization, which includes representation from governmental agencies concerned with aeronautics, together with experts from civil life, the technical committees act as coordinating agencies, providing effectively for the interchange of information and ideas and for the prevention of duplication.

In addition to its standing committees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The Committee has four principal technical committees: the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, the Committee on Aircraft Materials, and the Committee on Aircraft Structures. Under these committees there are nine standing subcommittees and seven special technical subcommittees. The membership of these groups is listed in Part II.

THE COMMITTEE ON AERODYNAMICS

Marked increases in the speed of aircraft have emphasized the importance of aerodynamic refinement of the engine installation, as well as of external contours. Compressibility phenomena assume an ever-increasing role as the speed of the airplane and its components approaches the velocity of sound. The aircraft propeller is most affected because the blades are everywhere moving at a velocity greater than that of the airplane, and the tip speed in some cases may exceed the velocity of sound.

Increased wing loadings result in greater emphasis on the use of high-lift devices in order that the landing speed may be maintained at a reasonable value. The need for efficient airfoil sections is more apparent than ever. The effect of increased aerodynamic cleanliness and small wings is to impose much more severe loading on aircraft in the event a spin is encountered, and rapid recovery from the spin is important in order to keep the structural loads within safe limits. High speeds also impose severe loads on windshields and pilot enclosures, and knowledge of these loads, as well as of efficient forms of windshields, is essential.

Special phases of the problems confronting the Committee on Aerodynamics are investigated under the cognizance of seven subcommittees, dealing respectively with meteorological problems, lightning hazards to aircraft, seaplanes, vibration and flutter, propellers, rotating-wing aircraft, and icing problems.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The loads imposed on the aircraft structure by atmospheric turbulence have a direct bearing on the necessary factor of safety in the design of the structure. Statistical knowledge of gust loads has been accumulated for many types of aircraft over the continental United States and over ocean routes.

The Committee is engaged in the investigation of the structure of atmospheric turbulence, with particular reference to the gusts encountered on the fronts of moving air masses. An especially equipped airplane has made exploratory flights into the fronts of such masses at various altitudes and has obtained records of the turbulence encountered. The analysis of the data obtained from these flights is in progress, and a scale whereby the degree of turbulence of the atmosphere may be classified is under consideration.

The encountering of heavy rainfall is also of interest because of possible effects on engine operation and on air-speed indicators. The work on these and other meteorological problems which the subcommittee has taken up during the year has been carried on in close collaboration with representatives of the United States Weather Bureau.

SPECIAL SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

A careful study has been made of all recorded lightning strikes to aircraft. The data have been analyzed and a summary report has been issued. These studies have yielded certain criteria as to conditions favorable for lightning discharges, and have contributed to the understanding of atmospheric processes entering into the accumulation of electricity. Simulated lightning strikes to components of aircraft have also been studied in the special high-voltage laboratories of the Gen-

eral Electric and Westinghouse companies, and practical information has been obtained on the physical effects of such strikes.

An indicator has been developed by a commercial manufacturer which indicates when an airplane is entering a region in which lightning may be encountered. Thus forewarned, it is possible for the pilot to change course and so decrease the liability of being struck by lightning.

SUBCOMMITTEE ON SEAPLANES

The trend towards increased wing and beam loading has resulted in a need for data on the maximum loads likely to be encountered by a seaplane landing in a wide variety of seas. The dynamic stability of the hull is also an important problem on which considerable research efforts are being expended.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

The use of wings of increased structural efficiency on high-speed long-range aircraft requires a thorough analysis of the flutter problem. Research on the various phases of flutter phenomena are being continued.

SUBCOMMITTEE ON PROPELLERS FOR AIRCRAFT

The subcommittee has given special attention to the problems of developing propellers which will maintain their efficiency when mounted on engines of very high power and aircraft of extremely high speed; and the committee's laboratories are conducting research on these problems.

SUBCOMMITTEE ON ROTATING-WING AIRCRAFT

The theoretical equations for the characteristics of a lifting rotor have been extended and simplified to facilitate determination of the effect of the various parameters on performance. The limitations of the theory have been reexamined and a method devised for determining the limit of application as affected by blade stalling.

SPECIAL SUBCOMMITTEE ON DE-ICING PROBLEMS

Extensive research has been conducted on the prevention of ice on aircraft, including investigations on an experimental airplane equipped to prevent the formation of ice on the windshield, wings, and tail surfaces through the use of heat. Various means of de-icing propellers are also being investigated.

THE COMMITTEE ON POWER PLANTS FOR AIRCRAFT

The trend towards increased size, wing loadings, range, and higher-altitude operation of aircraft has resulted in greater emphasis in power-plant development upon increased take-off power and power at altitude, better cruising fuel economy, and the recovery of waste heat energy. Higher engine output has made the study of the stresses in the moving parts desirable so that design factors may be established to provide maximum durability and minimum weight.

Special phases of the problems confronting the Committee on Power Plants for Aircraft are investigated under the cognizance of four subcommittees dealing respectively with aircraft fuels and lubricants, supercharger compressors, exhaust-gas turbines and intercoolers, and induction-system de-icing.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

The importance of superior fuels is evident both to insure the minimum consumption so essential to long-range operation and the maximum power for take-off and climb without detonation. Research on such fuels is in progress and a study is being made of the lubrication problem.

SPECIAL SUBCOMMITTEE ON SUPERCHARGER COMPRESSORS

The importance of obtaining good performance at extremely high altitudes is placing increasing emphasis on the aircraft-engine supercharger. Research has been conducted on the centrifugal type during the past year with the object of increasing its efficiency and output. A large amount of testing has also been conducted to improve the laboratory technique required for testing superchargers and to furnish a common basis for comparing the performance of different makes.

SPECIAL SUBCOMMITTEE ON EXHAUST-GAS TURBINES AND INTERCOOLERS

The long-range requirements of modern aircraft have made it essential to study waste-heat recovery methods in an effort to utilize a greater percentage of the available energy. Research is in progress on the use of exhaust gas in the most efficient manner, and also on intercoolers.

SPECIAL SUBCOMMITTEE ON INDUCTION-SYSTEM DE-ICING

The occurrence of ice in the induction system of an aircraft engine may cause a serious decrease in the power output of the engine. Research is in progress to determine the range of conditions under which ice occurs in the induction system of present day engines, and an investigation is also being made to obtain information on means of preventing its formation and removing it.

THE COMMITTEE ON AIRCRAFT MATERIALS

The search for aircraft materials with the highest possible ratio of strength to weight is never ending. In addition to aluminum alloys, magnesium alloys, stainless steel, plastic-impregnated and plastic-bonded plywoods show promise for use in aircraft structures. The work of the Committee on Aircraft Materials is handled in greater detail by three standing subcommittees dealing respectively with metals used in aircraft, miscellaneous materials and accessories, and welding problems. In addition, there has recently been organized a special subcommittee for study of metals for turbosupercharger wheels and buckets.

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

In addition to the need for metals having a high strength-weight ratio, the need arises for a material which will maintain its strength at high temperature. The effect of change of temperature on strength presents a real problem for aircraft which attain extremely high altitudes. Research on the durability and strength of many metals is in progress.

SPECIAL SUBCOMMITTEE ON METALS FOR TURBOSUPERCHARGER WHEELS AND BUCKETS

In view of the importance, mentioned above, of providing high-strength heat-resistant metals for turbosupercharger wheels and buckets, a special subcommittee was appointed to handle the problem.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The demand for substitute materials, and the development of improved synthetic resin glues and new plywood fabrication methods, have stimulated efforts to utilize plastics and plywood in aircraft construction. The properties of these new materials are being investigated.

SPECIAL SUBCOMMITTEE ON WELDING PROBLEMS

The increase in aircraft production has placed emphasis on the development of improved fabrication methods. The Committee has been engaged in basic research on the welding problems of aluminum and magnesium alloys, and further work is now under way. Problems in the welding of aircraft steels and other materials are also receiving attention.

THE COMMITTEE ON AIRCRAFT STRUCTURES

Special problems are associated with the use of shell-like aircraft structures. Buckling, stress distribution around cut-outs, diagonal tension beams, and strength of various types of fastenings are problems on which knowledge is essential in order to design efficient structures.

Knowledge of the loads imposed on aircraft structures arising from atmospheric disturbances and maneuvers involve both structural theory and aerodynamic investigation. The existing body of information on the magnitude and nature of these loads is being constantly increased through the collection of records of the accelerations experienced by aircraft in both military and civil operation. A further field for structural research is the determination of water loads imposed upon seaplane hull structures within the range of possible landing conditions.

SPECIAL COMMITTEE ON JET PROPULSION

A Special Committee on Jet Propulsion was appointed in order to review the scientific aspects of the propulsion of aircraft using reaction jets.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915, and the membership increased from 12 to 15 by act approved March 2, 1929 (U. S. C., title 50, sec. 151). Its membership is appointed by the President and consists of two representatives each of the War and Navy Departments from the offices in charge of military and naval aeronautics, two representatives of the Civil Aeronautics Administration (Civil Aeronautics Act of 1938), one representative each of the Smithsonian Institution, the United States Weather Bureau and the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter six serve for terms of five years. All the members serve as such without compensation. During the past year the following changes occurred in the membership of the main Committee:

Dr. Robert E. Doherty, President of the Carnegie Institute of Technology, Pittsburgh, Pa., resigned July 3, 1941, because of his assumption of additional responsibilities as Chairman of the Production Planning Board of the Office of Production Management.

To succeed Dr. Doherty the President, on July 23, 1941, appointed Dr. William F. Durand, Professor Emeritus of Mechanical Engineering, Leland Stanford Junior University, Palo Alto, Calif., for the balance of Dr. Doherty's term, expiring December 1, 1944.

Dr. Durand had previously served as a member of the Committee from 1915 to 1933, having been one of the original members appointed by President Wilson and having served two terms as Chairman during the period of World War I.

The President, having by Executive order of June 28, 1941, established the Office of Scientific Research and Development and appointed Dr. Vannevar Bush director thereof, Dr. Bush, on July 1, 1941, tendered his resignation as Chairman of the National Advisory Committee for Aeronautics and as Chairman of its Executive Committee. The Committee, on July 24, accepted with sincere regret Dr. Bush's resignation, effective July 31, 1941, and adopted a resolution expressing appreciation to Dr. Bush "for the time, energy, and inspiring leadership he has given to the work of the Committee."

The Committee, on July 24, 1941, elected Dr. Jerome C. Hunsaker, head of the Departments of Mechanical and Aeronautical Engineering at the Massachusetts Institute of Technology, Chairman and also Chairman of the Executive Committee, to serve from August 1, 1941, until the next annual meeting, October 23, 1941.

Under the rules and regulations governing the work of the Committee, as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee. On October 23, 1941, Dr. Jerome C. Hunsaker was reelected Chairman and Dr. George J. Mead was reelected Vice Chairman of the main Committee for the year ending October 22, 1942. Dr. Hunsaker was also reelected Chairman of the Executive Committee and Dr. Charles G. Abbot was reelected Vice Chairman of the Executive Committee.

The executive offices of the Committee, including the Office of Aeronautical Intelligence and the Office of Aeronautical Inventions, which had been located in the Navy Building, Washington, D. C., for more than 21 years, were removed in October 1941, to rented quarters, 1500 New Hampshire Avenue NW. This was done in order to provide for necessary expansion of the Navy and of the Committee.

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. It serves as the depository and distributing agency for the scientific and technical data on aeronautics comprising the results of Committee researches and also for similar information collected by the Committee from governmental and private agencies in this country and abroad. The data collected are classified, catalogued, and disseminated by this office.

RESEARCH FACILITIES

The Committee now has three major research stations: the Langley Memorial Aeronautical Laboratory, Langley Field, Va.; the Ames Aeronautical Laboratory, Moffett Field, Calif.; and the Aircraft Engine Research Laboratory, Cleveland, Ohio.

A description of research facilities added during the past year at the Langley and Ames laboratories is presented earlier in this report.

The Second Deficiency Appropriation Act, 1941, approved July 3, 1941, increased the limit of cost of the Aircraft Engine Research Laboratory at Cleveland, from $8,400,000 to $13,300,000 to meet increased construction and equipment costs and because of the need

of expanding the principal units of the laboratory to an extent that will permit research to be conducted under conditions more commensurate with expanding military requirements. The Cleveland laboratory is under construction and it is expected that actual research will start in some units during the summer of 1942.

The Second Supplemental National Defense Appropriation Act, 1942, approved October 28, 1941, increased the limit of cost of the Ames Aeronautical Laboratory from $10,000,000 to $16,207,500 to provide for the completion of the authorized construction program and for the addition of a high-speed low-turbulence wind tunnel. Seven units of the Ames Laboratory have been constructed and are busily engaged on urgent research projects with some units working on a two-shift basis.

Plans have been approved for the operation of the Langley Field laboratory generally on a two-shift basis and in some sections on a three-shift basis. This will require more than 100 percent increase in personnel, which increase has been authorized by the Congress.

COOPERATION WITH THE AVIATION INDUSTRY

The Committee's research program has always been shaped to give due consideration to the immediate problems of the industries designing, building, and operating aircraft. Through correspondence and through personal contacts, the Committee has obtained suggestions and recommendations from aircraft manufacturers and operators as to investigations that are considered by them to be especially important. This practice has been expanded and strengthened during the past year because of the urgency of problems that arise in connection with the National Defense Program. The research facilities of the laboratories, with the expectation of those devoted to longer-range fundamental projects, have been utilized for the conduct of applied research on specific airplane designs about to be built or actually under construction.

The number of technical representatives of the aircraft industry visiting the Committee's laboratories is so great and the investigations conducted for the improvement of strictly military designs are so numerous that the Army Air Corps maintains a liaison organization at the laboratories to facilitate the handling of problems presented by military contractors, and the Navy Bureau of Aeronautics also maintains a liaison officer. The Committee also arranges for staff specialists to confer with Government contractors in their own plants. Through these arrangements the Committee is able to render a maximum of service and to be better informed on developments that may influence its research program.

A cooperative action of special significance is the functioning during the past year of the "Power Plant Installation Group" at the Langley Field laboratory. This working group is composed of NACA staff members and designing engineers from virtually all of the makers of military aircraft and military engines. Its objective is the application of research findings to the practical requirements of power plant installations for military airplanes. Flight results from some of the arrangements that have been thus evolved indicate the work of this group to be highly effective in anticipating and solving engine-installation difficulties.

Still another evidence of healthy cooperation is the increasing number of visits of airplane designers to the Committee's laboratories for consultation regarding designs that are in the formative stage. With a tentative arrangement of the complete airplane to consider, the Committee's staff may suggest the use of research information that may be beneficial to performance or flying qualities, or may point out difficulties that can be anticipated as a result of laboratory experience.

Cooperation with the aircraft industry also benefits the members of the staffs of the Committee's laboratories through first-hand contacts with the men working on airplane design and development problems. Through such contacts, the technical staff obtains an appreciation of the points of view of the designers.

In view of the military significance of the Committee's research results and because of the pressure of work, it has again been found to be impractical to hold a general conference of representatives of all branches of aviation to review the work done during the year. Instead, smaller conferences have been arranged for representatives designated by the military services whenever a field of research has reached a stage where practical applications can be made, and where the information can be transmitted most advantageously by first hand means.

With the present rapid advance in the art research results should be made available at the earliest possible date to those units of the industry which have been designated by the Army or Navy to receive restricted or confidential information. When the results of an investigation appear at some stage of the program to be of special interest and value to designers, the Committee makes the information immediately available, usually by issuing the data in advance restricted or confidential form.

AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with

that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the inventions section considered approximately 2,600 inventions, suggestions, and designs pertaining to aeronautics. Careful consideration was given to these proposals and their merits were evaluated. The necessary correspondence was conducted to advise the submitters of the evaluations, and personal interviews were held with inventors who visited the Committee's offices.

In August 1940, the National Inventors Council was created by the Secretary of Commerce with the concurrence of the President to serve as a central Government clearing house to which can be submitted inventions and suggestions that might prove valuable to the national defense. The Committee's Director of Aeronautical Research, Dr. George W. Lewis, serves as chairman of the Council's Technical Committee on Aircraft and Aeronautics. During the past year the Council has referred to the Committee for comment many of the proposals dealing with aeronautics submitted to it for consideration.

COORDINATION OF AERONAUTICAL RESEARCH

The Office of the Coordinator of Research has been active in maintaining contact with the aircraft industry and with scientific and educational institutions. A comprehensive study has been made of research facilities adapted to investigations on aeronautical problems.

During the past year 385 visits were made to manufacturers and to scientific and educational institutions. Thirty-six contracts for scientific investigations and reports were made with 18 educational institutions.

MEMBERSHIP OF SUBCOMMITTEES

A discussion of the scope of activity of each of the standing and special technical committee's and subcommittees has been presented in part I. The organization of the subcommittees is as follows:

COMMITTEE ON AERODYNAMICS

Dr. Edward Warner, Chairman.
Dr. Hugh L. Dryden, National Bureau of Standards, Vice Chairman.
Edmund T. Allen, Boeing Aircraft Company.
Lt. Col. Howard Z. Bogert, Air Corps, United States Army. Matériel Division, Wright Field.
Lt. Col. Franklin O. Carroll, Air Corps, United States Army. Matériel Division, Wright Field.
Marion P. Crews, Civil Aeronautics Administration.
Commander Walter S. Diehl, United States Navy.
John Easton, Civil Aeronautics Administration.
Dr. Jerome C. Hunsaker.
Eastman N. Jacobs, National Advisory Committee for Aeronautics.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex officio member).
Prof. Otto Koppen, Massachusetts Institute of Technology.
John G. Lee, United Aircraft Corporation.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Dr. Clark B. Millikan, California Institute of Technology.
Robert R. Osborn, Bell Aircraft Corporation.
Commander John E. Ostrander, Jr., United States Navy.
H. J. E. Reid, National Advisory Committee for Aeronautics.
Fred E. Weick, Engineering and Research Corporation.
John B. Wheatley, The Glen L. Martin Company.
Theodore P. Wright, Office of Production Management.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Dr. F. W. Reichelderfer, Chairman.
Col. E. S. Gorrell, Air Transport Association of America.
Prof. H. G. Houghton, Massachusetts Institute of Technology.
Dr. W. J. Humphreys, United States Weather Bureau.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex officio member).
R. W. Knight, Civil Aeronautics Administration.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Delbert M. Little, United States Weather Bureau.
Dr. Charles F. Marvin, Washington, D. C.
Capt. Arthur F. Merewether, Air Corps, United States Army.
Lt. Comdr. Howard T. Orville, United States Navy.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Dr. C. G. Rossby, United States Weather Bureau.
Prof. A. F. Spilhaus, New York University.

SPECIAL SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

Delbert M. Little, United States Weather Bureau, Chairman.
Dr. O. H. Gish, Carnegie Institution of Washington.
Lt. Comdr. M. P. Hanson, United States Naval Reserve.
Charles H. Helms, National Advisory Committee for Aeronautics.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex officio member).
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
K. B. McEachron, General Electric Company.
Dr. Irving R. Metcalf, Civil Aeronautics Administration.
E. J. Minser, Transcontinental & Western Air, Incorporated.
Maj. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Peter Sandretto, United Air Lines Transport Corporation.
Dr. F. B. Silsbee, National Bureau of Standards.

SUBCOMMITTEE ON SEAPLANES

Captain H. C. Richardson, United States Navy, Chairman.
E. T. Allen, Boeing Aircraft Company.

Prof. K. S. M. Davidson, Stevens Institute of Technology.
Commander W. S. Diehl, United States Navy.
Michael Gluhareff, Vought-Sikorsky Aircraft Division.
Capt. H. E. Gray, Pan American Airways.
S. Paul Johnston, National Advisory Committee for Aeronautics (ex officio member).
Paul E. Hovgard, The Glenn L. Martin Company.
B. V. Korvin-Kroukovsky, Edo Aircraft Corporation.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Maj. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
A. L. Morse, Civil Aeronautics Administration.
Capt. H. E. Saunders, United States Navy.
H. A. Sutton, Consolidated Aircraft Corporation.
Starr Truscott, National Advisory Committee for Aeronautics.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

H. J. E. Reid, National Advisory Committee for Aeronautics, Chairman.
Lt. Comdr. J. P. Den Hartog, United States Naval Reserve.
Capt. Frederick R. Dent, Jr., Air Corps, United States Army, Matériel Division, Wright Field.
Commander W. S. Diehl, United States Navy.
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Brig. Gen. O. P. Echols, Air Corps, United States Army.
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Capt. S. M. Kraus, United States Navy.
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John F. Victory, Secretary.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

Because of the national emergency, and at the request of the Army and the Navy, the publications of the Committee presenting the results of its researches are classified as confidential or restricted, and as such are not available for general distribution.

To meet the needs of the Army, the Navy, and aircraft, engine, and accessories manufacturers who are contractors to the Army and the Navy, the Committee has inaugurated two new series of publications which are issued as advance reports. The distribution of these is limited for security.

The series known as technical memorandums contains translations and reproductions of important foreign aeronautical articles. This series is available to the public.

FINANCIAL REPORT

APPROPRIATIONS FOR FISCAL YEAR 1941

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1941, as contained in the Independent Offices Appropriation Act approved April 18, 1940, was $2,775 000. The amount expended during 1941 was $2,774,988, itemized as follows:

Personal services	$1,806,535
Supplies and materials	223,075
Communication service	10,291
Travel expenses	40,203
Transportation of things	18,539
Furnishing of electricity	68,171
Repairs and alterations	46,580
Special and miscellaneous investigations	100,000
Contracts for research	120,000
Equipment	341,594
Expended and obligated	2,774,988
Unexpended balance	12
Total, general appropriation	2,775,000

The appropriation for printing and binding was $25,000, of which $24,978 was expended.

The Independent Offices Appropriation Act, approved April 18, 1940, also provided $1,000,000 for continuing the construction of additional facilities at Langley Field, Va., an initial sum of $2,140,000 having been provided for this purpose in the Second Deficiency Appropriation Act, fiscal year 1939, approved May 2, 1939. Of this fund, the amount of $1,220,741 was obligated during the fiscal year 1941.

The Independent Offices Appropriation Act, approved April 18, 1940, also provided $4,200,000 for continuing the construction and equipment of an additional research laboratory at Moffett Field, Calif., an initial amount of $1,890,980 having been provided for this purpose in the Third Deficiency Appropriation Act, fiscal year 1939, approved August 9, 1939, which act also provided for entering into contracts not to exceed a total of $10,000,000. Of this fund, the amount of $2,276,791 was obligated during the fiscal year 1941.

The First Supplemental National Defense Appropriation Act, 1941, approved June 26, 1940, provided $2,000,000 for beginning the construction and equipment of an aircraft engine research laboratory, on a site to be selected by the Committee, and authorized entering into contracts for construction and equipment of such buildings and facilities, including the purchase of land and rights-of-way, at a total cost of not to exceed $8,400,000. Cleveland, Ohio, was selected as the site for this new laboratory, and the amount of $1,165,869 was obligated during the fiscal year 1941.

The First Supplemental National Defense Appropriation Act, 1941, approved June 26, 1940, also provided $1,200,000 for the construction and equipment at Langley Field, Va., of a power-generating plant. Of this amount $1,151,326 was obligated during the fiscal year 1941.

The amount of $1,460 was received during the fiscal year 1941 for two special deposit accounts to cover the cost of scientific investigations for manufacturers. This amount, with $10,000 remaining from the previous fiscal year, made the amount of $11,460 available for four tests. Two investigations were completed during 1941, resulting in a deposit of $5,628.24 in the Treasury to the credit of Miscellaneous Receipts, as proceeds, and the return of $1,571.76 to depositors.

APPROPRIATIONS FOR FISCAL YEAR 1942

The general appropriation for the fiscal year 1942, as contained in the Independent Offices Appropriation Act, 1942, approved April 5, 1941, was $4,567,890, and the amount provided for printing and binding was $25,000. This act also provided $3,409,020 for continuing construction and equipment of the Ames Aeronautical Laboratory at Moffett Field, Calif., and $5,600,000 for continuing construction and equipment of the aircraft engine research laboratory at Cleveland, Ohio. The total amount provided for the Committee in this act therefore was $13,601,910.

The Second Deficiency Appropriation Act, 1941, approved July 3, 1941, provided an additional amount of $465,000 for the general purposes contained in the Independent Offices Appropriation Act, 1942. An additional amount of $875,000 was also provided for continuing the construction and equipment of additional laboratory buildings and research facilities at Langley Field, Va. This act also provided for an increase from $8,400,000 to $13,300,000 in the total cost of construction and equipment of the aircraft engine research laboratory at Cleveland, Ohio.

The Second Supplemental National Defense Appropriation Act, 1942, approved October 28, 1941, provided an additional amount of $1,162,575 for the general pur-

poses contained in the Independent Offices Appropriation Act, 1942. An additional amount of $261,425 was also included in this act for continuing the construction and equipment of additional laboratory facilities at Langley Field, Va. This act also provided for an increase from $10,000,000 to $16,207,500 in the total cost of construction and equipment of the Ames Aeronautical Laboratory at Moffett Field, Calif.

CONCLUSION

This country has embarked upon a tremendous aircraft production program. Its success, however, will depend not only on the number of airplanes produced but even more on their performance. Improvement in performance depends upon research. Adequate research requires modern and adequate facilities and trained personnel.

The recent establishment of additional research laboratories at Moffett Field, Calif., and at Cleveland, Ohio, and enlargement of facilities at Langley Field, Va., will, when authorized construction is completed, mean an increase of about two hundred per cent in the Committee's research facilities. The staff to man the new facilities and to operate them on a two-shift and three-shift basis is being organized and trained.

It is essential that each new type of aircraft have performance superior to its predecessors. Through effective collaboration with the Army, the Navy, the Civil Aeronautics Administration, and the industry, improvement in performance has been materially accelerated by incorporating research results in new designs. Only from sustained and farsighted scientific research can the country have assurance that from its vast expenditures it will have aircraft at least equal to the best produced by others.

Respectfuily submitted.

National Advisory Committee
For Aeronautics,
Jerome C. Hunsaker, *Chairman.*

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Twenty-eighth Annual Report

of the

National Advisory Committee for Aeronautics

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TWENTY-EIGHTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1942

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LETTER OF TRANSMITTAL

To the CONGRESS OF THE UNITED STATES:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Twenty-eighth Annual Report of the Committee covering the fiscal year 1942.

FRANKLIN D. ROOSEVELT.

THE WHITE HOUSE,
March 30, 1943.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEETING, WASHINGTON, D. C., DECEMBER 17, 1942

Left to right: Burden, Durand, Chidlaw (representing Arnold and Echols), Bush, Orville Wright, Lewis, Hunsaker, Victory, Abbot, T. P. Wright, Warner, Briggs, Kraus, Reichelderfer (Admiral McCain and Dr. Mead not present).

LETTER OF SUBMITTAL

National Advisory Committee for Aeronautics,
Washington, D. C., March 26, 1943.

The President,
The White House, Washington, D. C.

Dear Mr. President: In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C. title 50, sec. 153), I have the honor to submit herewith the Twenty-eighth Annual Report of the National Advisory Committee for Aeronautics, covering the fiscal year 1942.

During the past year the fighting forces of the United Nations have taken the offensive with substantial support from their air forces. The effectiveness of the air forces is in direct proportion to the energy and the resources which have been devoted to the technical development of their aircraft. Only by constant research can we be assured of providing airplanes of superior performance.

The Committee's research facilities and scientific staff have been greatly expanded and strengthened during the past 4 years with generous appropriations by the Congress. In our first year of war, day and night shifts have been working on urgent research projects in our three large laboratories in Virginia, Ohio, and California. With these facilities the Committee has been able to meet the important research requirements of the military services.

The general manner in which this research has been organized and conducted during 1942 is described in this report. In the interest of military security, technical matter has been omitted.

Respectfully submitted,

Jerome C. Hunsaker, *Chairman.*

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, 1500 NEW HAMPSHIRE AVENUE NW, WASHINGTON, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 50, sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

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Cambridge, Mass.

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Director, National Bureau of Standards.

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Secretary, Smithsonian Institution.

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Special Assistant to the Secretary of Commerce.

VANNEVAR BUSH, Sc. D., Director,
Office Scientific Research and Development, Washington, D. C.

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JOHN S. MCCAIN, Rear Admiral, United States Navy, Chief, Bureau of Aeronautics, Navy Department.

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Washington, D. C.

FRANCIS W. REICHELDERFER, Sc. D.,
Chief, United States Weather Bureau.

EDWARD WARNER, Sc. D.,
Civil Aeronautics Board,
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ORVILLE WRIGHT, Sc. D.,
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THEODORE P. WRIGHT, Sc. D.,
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War Production Board.

GEORGE W. LEWIS, *Director of Aeronautical Research* — JOHN F. VICTORY, *Secretary*

HENRY J. E. REID, *Engineer in Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*

SMITH J. DEFRANCE, *Engineer in Charge, Ames Aeronautical Laboratory, Moffett Field, Calif.*

EDWARD R. SHARP, *Administrative Officer, Aircraft Engine Research Laboratory, Cleveland Airport, Cleveland, Ohio*

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AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS

AIRCRAFT STRUCTURES
INVENTIONS & DESIGNS
OPERATING PROBLEMS

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANGLEY FIELD, VA

AMES AERONAUTICAL LABORATORY

MOFFETT FIELD, CALIF

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CLEVELAND AIRPORT, CLEVELAND, OHIO

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight.

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Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics

TWENTY-EIGHTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *February 25, 1943.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151), which established the National Advisory Committee for Aeronautics, the Committee submits herewith this Twenty-eighth Annual Report, for the fiscal year 1942. Since the requirements for military secrecy prevent mention of specific projects, the report has been edited to present only a general picture of the Committee's activity.

Tactical significance of NACA work.—The events of the past year, during which the United Nations have assumed the offensive with the aid of vastly increased air power, have indicated more clearly than ever the necessity for continuous technical development of aircraft. The need for new and improved types of combat airplanes has been strikingly demonstrated by experience gained in the operation of our aircraft in all corners of the globe. The military necessity for meeting the best aircraft developed by the enemy and for building new types for the kind of warfare anticipated by the High Command has confronted American aeronautical engineers.

In contact with the enemy in all parts of the world, new problems must be met by our flyers and, in turn, new requirements are imposed on our manufacturers. In some cases the new requirements cannot be met without extensive research and experimentation. Sometimes, improvements to correct defects in, or to increase the performance of, existing airplanes or equipment can quickly be found. At other times, a military requirement demands the search for an entirely new solution, unknown to the present art.

More rarely, the discovery that enemy aircraft are in some features superior to American aircraft, demands urgent efforts to make up the deficiency. Research problems arise through the expressed needs of the armed services for improved performance, or in some cases out of the Committee's own experience and foresight, or again, as the result of unanticipated problems created by the enemy on the fighting fronts. All of these conditions, the Committee's staff must be prepared to meet. It may be accepted that the maintenance of supremacy in the air will be essential to final victory and the Committee feels that the contributions of its researches to the improved performance and effectiveness of American military aircraft are vital to the success of the national aircraft program. The Committee's activities are inseparably interwoven, not only with future designs of aircraft but likewise with aircraft in the production stage. For example, at the request of either the Army or the Navy, there are an average of 45 representatives of aircraft industries daily at the Langley Field laboratories. These men stay for a few days or a few weeks, consulting and advising, and waiting for solutions to their urgent problems. Solutions are promptly relayed to factories, and find immediate incorporation in types of aircraft already in production, or whose production has been held up awaiting answers from the Committee's laboratories.

That American aircraft in actual combat have proved to be the equal or better in almost every respect than those which they oppose, depends in no small measure on the Committee's researches. As the result of continuing research, airplanes of still greater effectiveness are constantly being developed.

Expansion of research activity.—It is most fortunate that the need for a great increase in aircraft research and development activity was recognized by the Congress several years ago, and that at the time of Pearl Harbor the Committee was so well prepared to handle its vital and expanding war assignments.

Beginning in 1937, the growing importance of the airplane to the national defense and to the Nation's domestic economy, led the Committee to recommend, and the Congress to approve, a marked expansion in scientific research facilities. That year marked the beginning of a construction program which has been supported by appropriations for new construction amounting to $38,507,425, and an expansion of staff from 446 to 4,410 estimated for 1944.

NEW FACILITIES.—A group of three new buildings at the Langley Memorial Aeronautical Laboratory, at Langley Field, Va. (Left to right) Stability Wind Tunnel, Central Heating Plant, and Power Generating Plant. The Power Plant supplies electric power for the drive motors of all large wind tunnels at Langley Field.

NEW WIND TUNNEL.—High-speed wind tunnel recently placed in operation at the Langley Memorial Aeronautical Laboratory, at Langley Field, Va.

FLIGHT RESEARCH LABORATORY.—At the Ames Aeronautical Laboratory at Moffett Field, Calif. Experimental airplanes are specially rigged in this hangar for flight research. Engineers of flight research section utilize office space.

ENGINE PROPELLER TEST HOUSE.—First research facility placed in operation at the new NACA Aircraft Engine Research Laboratory at Cleveland, Ohio.

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RESEARCH BEGINS AT NEW LABORATORY.—A group of NACA officials are pictured at the opening of research at the new Aircraft Engine Research Laboratory at Cleveland, Ohio. Research was begun months ahead of schedule in May 1942.

The Langley Memorial Aeronautical Laboratory at Langley Field, Va., and the Ames Aeronautical Laboratory at Moffett Field, Calif., started in 1939, are working on a three-shift basis as far as practicable, and are wholly engaged on problems referred to the Committee by the Army and Navy. The new Aircraft Engine Research Laboratory at Cleveland, Ohio, is nearing completion and is already busily engaged on engine problems. It will operate on a two- and three-shift basis as soon as conditions permit.

During the past year, the following additional research facilities have been placed in operation:

At Langley Field, Va., a new towing basin for studying flying-boat hulls and high-speed surface craft; an impact basin for investigating the loads encountered in the landing of flying boats; a new fabrication and finishing shop for the construction of models and apparatus for research investigations; and a combined office and warehouse building to serve the various research laboratories.

At Cleveland, Ohio, the engine-propeller test house, fuels and lubricants laboratory, technical service building, flight research laboratory, utilities building, heating plant, two electric substations, and an administration building. The engine research building is nearly completed and is in partial operation. Still under construction are the altitude wind tunnel, the icing wind tunnel, and the exhauster and refrigerating buildings for these wind tunnels.

At the Moffett Field Laboratory, there are under construction a full-scale wind tunnel with operating section 80 feet wide by 40 feet high, a high-speed two-dimensional, low-turbulence, variable-density wind tunnel, and an administration building.

In addition, research contracts have been placed with 24 university laboratories for research on 54 special problems. In this way the Committee has provided for the conduct of research on many problems without increasing unnecessarily its facilities or personnel, and has made effective use of existing private facilities without duplication of effort.

COMMITTEE ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915, and the membership increased from 12 to 15 by act approved March 2, 1929 (U. S. C., title 50, sec. 151). Its membership is appointed by the President and consists of two representatives each of the War and Navy Departments from the offices in charge of military and naval aeronautics, two representatives of the Civil Aeronautics Authority (Civil Aeronautics Act of 1938), one representative each of the Smithsonian Institution, the United States Weather Bureau, and the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical

engineering or its allied sciences." These latter six serve for terms of 5 years. All the members serve as such without compensation. During the past year, the following changes occurred in the membership of the main Committee:

Maj. Gen. George H. Brett, United States Army, was relieved on January 23, 1942, because of his transfer to foreign duty, and Maj. Gen. O. P. Echols, commanding general of the Matériel Command, Army Air Forces, was appointed to succeed General Brett.

Brig. Gen. Donald H. Connolly, Administrator of the Civil Aeronautics Administration, resigned on January 15, 1942, because of his call to active duty in the Army Air Forces.

To succeed Brigadier General Connolly, the President, on May 14, 1942, appointed Dr. Edward Warner, member of the Civil Aeronautics Board, as one of the two official representatives on the Committee from the Civil Aeronautics Authority. Dr. Warner had been serving on the Committee as one of the six members appointed from private life.

On May 14, 1942, the President appointed Dr. Theodore P. Wright, of the Aircraft Division of the War Production Board, to succeed Dr. Edward Warner as a member from private life, for the balance of Dr. Warner's term, expiring December 1, 1946.

Hon. Robert H. Hinckley resigned on July 1, 1942, because of his resignation as Assistant Secretary of Commerce.

Hon. William A. M. Burden, Special Assistant to the Secretary of Commerce, was appointed by the President, on August 8, 1942, a member of the Committee to succeed Mr. Hinckley.

Rear Admiral John H. Towers, United States Navy, Chief of the Bureau of Aeronautics, resigned on September 28, 1942, because of his transfer to duty away from Washington.

On October 6, 1942, the President appointed, as Admiral Towers' successor, the newly appointed Chief of the Bureau of Aeronautics, Rear Admiral John S. McCain, United States Navy.

In accordance with the regulations governing the organization of the Committee, as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee. On October 22, 1942, Dr. Jerome C. Hunsaker was reelected Chairman and Dr. Lyman J. Briggs was elected Vice Chairman of the main Committee succeeding Dr. George J. Mead. Dr. Hunsaker was also reelected Chairman of the Executive Committee and Dr. Charles G. Abbot was reelected Vice Chairman of the Executive Committee.

TECHNICAL COMMITTEES

In order to obtain the most competent advice on the many highly specialized problems of aeronautics with which the main Committee is concerned, a number of subcommittees are appointed for the purpose of making recommendations to the main Committee regarding programs of research to be conducted in their respective fields. These technical subcommittees comprise representatives of the various Governmental organizations concerned, as well as individuals from the aviation industry, and from private life. They constitute the best-informed experts in the Nation in their particular fields. Their discussions are extremely valuable in providing for the effective exchange of information and ideas and in advising on research programs.

The main Committee has principal technical committees which cover the following fields: Aerodynamics, Power Plants, Aircraft Materials, Aircraft Structures, and Operating Problems. Under these principal technical committees are a number of technical subcommittees which cover specific problems in these broad fields. The organization and scope of activity of each of these groups which, incidentally, also serve without compensation, are given in the succeeding pages.

COMMITTE ON AERODYNAMICS

In addition to supervising activities of five subcommittees dealing with the subjects of seaplanes, vibration and flutter, propellers, dual-rotation propellers, and rotating wing aircraft, the Committee on Aerodynamics studies general problems such as the cowling and cooling of the engine, compressibility phenomena encountered at high air speeds, stability, control, design of airfoil sections and control surfaces, and range, capacity, and ceiling of aircraft. These problems have become more numerous and difficult as well as of more vital importance as improvements in airplane design have increased the speed and altitude of operation. The membership of this committee during the past year was:

Dr. Theodore P. Wright, Aircraft Branch, War Production Board, Chairman.

Dr. Hugh L. Dryden, National Bureau of Standards, Vice Chairman.

John L. Atwood, North American Aviation, Inc.

Don R. Berlin, General Motors Corporation.

Col. Howard Z. Bogert, United States Army, Army Air Forces.

Brig. Gen. Franklin O. Carroll, United States Army, Army Air Forces.

Capt. Walter S. Diehl, United States Navy, Navy Department.

John Easton, Civil Aeronautics Administration.

Harold D. Hoekstra, Civil Aeronautics Administration.

Eastman N. Jacobs, National Advisory Committee for Aeronautics.

Clarence L. Johnson, Lockheed Aircraft Corporation.

Prof. Otto Koppen, Massachusetts Institute of Technology.

John G. Lee, United Aircraft Corporation.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Dr. Clark B. Millikan, California Institute of Technology.

Capt. J. E. Ostrander, United States Navy, Navy Department.

Dr. William Bailey Oswald, Douglas Aircraft Co., Inc.

H. J. E. Reid, National Advisory Committee for Aeronautics.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Igor Sikorsky, United Aircraft Corporation.
Dr. Edward Warner, Civil Aeronautics Board.

SUBCOMMITTEE ON SEAPLANES

Military operation of seaplanes has resulted in large increases in wing and beam loadings. The dynamic stability during take-off and landing with overloads, an important problem, has received considerable study. Data on the hydrodynamic loads acting upon hulls for various conditions of the water and of aircraft loading have also been obtained. Membership of this subcommittee during 1942 was:

Capt. H. C. Richardson, United States Navy, Navy Department, Chairman.
E. T. Allen, Boeing Aircraft Co.
Prof. K. S. M. Davidson, Stevens Institute of Technology.
Capt. Walter S. Diehl, United States Navy, Navy Department.
Michael Gluhareff, United Aircraft Corporation.
Capt. H. E. Gray, Pan American Airways.
Paul E. Hovgard, the Glenn L. Martin Co.
B. V. Korvin-Kroukovsky, Edo Aircraft Corporation.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lt. Col. Charles K. Moore, United States Army, Army Air Forces.
Alan L. Morse, Civil Aeronautics Administration.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Capt. H. E. Saunders, United States Navy, Navy Department.
H. A. Sutton, Consolidated Aircraft Corporation.
Starr Truscott, National Advisory Committee for Aeronautics.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

Each new design of a high-performance military air plane requires a thorough analysis of its flutter characteristics. In this connection both theoretical and experimental investigations of the various phases of the flutter phenomena have been extended. The following were members of this subcommittee during 1942:

H. J. E. Reid, National Advisory Committee for Aeronautics, Chairman.
E. Forest Critchlow, Civil Aeronautics Administration.
Lt. Comdr. J. P. Den Hartog, United States Naval Reserve, Navy Department.
Col. Frederick R. Dent, Jr., United States Army, Army Air Forces.
Commander Robert S. Hatcher, United States Navy, Navy Department.
Capt. C. L. Helber, United States Navy, Naval Aircraft Factory.
Charles H. Helms, National Advisory Committee for Aeronautics.
Prof. Otto C. Koppen, Massachusetts Institute of Technology.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Albert London, Civil Aeronauties Administration.
Dr. Walter Ramberg, National Bureau of Standards.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Lt. Benjamin Smilg, United States Army, Army Air Forces.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

SUBCOMMITTEE ON PROPELLERS FOR AIRCRAFT

Increases in engine power and speed, especially at high altitude, have required intensification of propeller research in the Committee's laboratories. The subcommittee membership during 1942 comprised the following:

Frank W. Caldwell, United Aircraft Corporation, Chairman.
David Biermann, National Advisory Committee for Aeronautics.
Werner J. Blanchard, Aeroproducts Division, General Motors Corporation.
Col. Howard H. Couch, United States Army, Army Air Forces.
Dr. Hugh L. Dryden, National Bureau of Standards.
Louis H. Enos, Curtiss-Wright Corporation.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Erle Martin, Hamilton Standard Propellers.
Commander W. B. Mechling, United States Navy, Navy Department.
John C. Morse, Civil Aeronautics Administration.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Fred E. Weick, Engineering and Research Corporation.

SUBCOMMITTEE ON VIBRATION OF DUAL-ROTATION PROPELLERS FOR AIRCRAFT

Before dual-rotation propellers could be used to absorb efficiently and satisfactorily the increased power of new aircraft engines, it was necessary to investigate both theoretically and experimentally the vibration characteristics of these propellers. Extensive research on this subject was done in the Committee's laboratories. The membership of the subcommittee during the past year was as follows:

Frank W. Caldwell, United Aircraft Corporation, Chairman.
Capt. Rico Botta, United States Navy, Navy Department.
Col. Howard H. Couch, United States Army, Army Air Forces.
Lt. Comdr. J. P. Den Hartog, United States Naval Reserve, Navy Department.
R. M. Guerke, Curtiss-Wright Corporation.
Charles M. Kearns, Jr., United Aircraft Corporation.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

SUBCOMMITTEE ON ROTATING-WING AIRCRAFT

During the past year, the Committee has made important theoretical studies contributing to the further development of autogiros, gyroplanes, and helicopters. The following were members of this subcommittee:

John Easton, Civil Aeronautics Administration, Chairman.
Frederick J. Bailey, Jr., National Advisory Committee for Aeronautics.
Capt. Walter S. Diehl, United States Navy, Navy Department.

Col. Hollingsworth F. Gregory, United States Army, Army Air Forces.
Prof. Alexander Klemin, New York University.
A. E. Larsen, Pecker-Simpson-Gladeck & Assoc.
W. Laurence LePage, Platt-LePage Aircraft Co.
Dr. G. W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
R. H. Prewitt, Kellett Autogiro Corporation.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
I. I. Sikorsky, United Aircraft Corporation.
Paul H. Stanley, G. & A. Aircraft, Inc.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

The military necessity for airplanes capable of carrying greater loads at higher speeds and altitudes over longer distances, and under tropical and arctic conditions, has presented a multitude of new problems for aircraft engine designers. In the case of pursuit and fighter type airplanes, it has been necessary to furnish increased horsepower for brief take-off and combat intervals, while in long-range airplanes, fuel economy and reliability have had to be improved. In almost all combat type airplanes, improvements in supercharging and engine cooling have been necessary.

In attacking these various problems, the Power Plants Committee has been assisted by five subcommittees which cover problems in the following fields: Exhaust gas turbines; supercharger compressors, heat exchangers; fuels and lubricants; and lubrication, friction and wear. The membership of the Power Plants Committee during 1942 was:

Dr. George J. Mead, Chairman.
Prof. E. S. Taylor, Massachusetts Institute of Technology, Vice Chairman.
Capt. Rico Botta, United States Navy, Navy Department.
Frank W. Caldwell, United Aircraft Corporation.
Dr. H. C. Dickinson, National Bureau of Standards.
R. M. Hazen, General Motors Corporation.
S. D. Heron, Ethyl Corporation.
L. S. Hobbs, Pratt & Whitney Aircraft.
Carlton Kemper, National Advisory Committee for Aeronautics.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Arthur Nutt, Wright Aeronautical Corporation.
Col. E. R. Page, United States Army, Army Air Forces.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Stephen Rolle, Civil Aeronautics Administration.

EXHAUST GAS TURBINES SUBCOMMITTEE

The problems arising in the design of turbines, particularly those utilizing the energy in the engine exhaust gases to drive the engine supercharger, have received the attention of this group. Increased efficiency of the turbine itself as well as greater utilization of the available energy in the fuel burned in the cylinder has been the objective of this subcommittee. Because of the relation of various components in the engine system, this subcommittee has also studied the over-all relations of engine power, supercharging, back pressure, and turbine output. The following were members of the subcommittee in 1942:

John G. Lee, United Aircraft Corporation, Chairman.
A. L. Berger, Army Air Forces.
Rudolph Birmann, Turbo Engineering Corporation.
K. A. Browne, Wright Aeronautical Corporation.
Opie Chenoweth, Army Air Forces.
S. R. Puffer, General Electric Co.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
E. S. Thompson, General Electric Co.
Commander C. J. Pfingstag, United States Navy, Navy Department.
Benjamin Pinkel, National Advisory Committee for Aeronautics.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).

SUBCOMMITTEE ON SUPERCHARGER COMPRESSORS

One of the most valuable contributions of this subcommittee has been a standardization of methods of testing supercharging equipment. Valuable studies have also been made of designs of various superchargers with a view to increasing the efficiency and output of these compressors. The 1942 membership of this subcommittee was as follows:

Kenneth Campbell, Wright Aeronautical Corporation, Chairman.
Rudolph Birmann, Turbo Engineering Corporation.
Lt. William Bollay, United States Naval Reserve, Navy Department.
Opie Chenoweth, Army Air Forces.
Norman A. Dunnells, Pratt & Whitney Aircraft.
W. J. King, General Electric Co.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
V. G. Raviolo, Ford Motor Co.
Dr. J. T. Rettaliata, Allis-Chalmers Manufacturing Co.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Oscar W. Schey, National Advisory Committee for Aeronautics.
Commander S. B. Spangler, United States Navy, Navy Department.
John Stack, National Advisory Committee for Aeronautics.

SUBCOMMITTEE ON HEAT EXCHANGERS

This subcommittee, which held its first meeting on May 11, 1942, was formed for the purpose of studying in greater detail the design of intercoolers and heat exchangers of various types used in aircraft. The problems of de-icing, cabin heating, intercooling, and flame suppression have received the consideration of this group. The following are members:

Prof. W. H. McAdams, Massachusetts Institute of Technology, Chairman.
Lt. Comdr. A. L. Baird, United States Navy, Navy Department.
M. J. Brevoort, National Advisory Committee for Aeronautics.
Dr. Allan P. Colburn, University of Delaware.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Dr. John Marchant, Pratt & Whitney Aircraft.
Rollin Hosmer Norris, General Electric Co.
Benjamin Pinkel, National Advisory Committee for Aeronautics.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
L. P. Saunders, General Motors Corporation.
Edmund C. Sulzman, Wright Aeronautical Corporation.
Weldon Worth, Army Air Forces.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

The performance of aircraft engines under combat conditions requires the best fuel that can be made available. Research on the various components of aviation fuel is in progress to insure that those of highest quality are utilized. Research on lubricants is in progress both in the Committee's laboratory and in cooperating laboratories. The 1942 membership was as follows:

Prof. W. G. Whitman, War Production Board, Chairman.
S. D. Heron, Ethyl Corporation, Vice Chairman.
Dr. D. P. Barnard, Standard Oil Co. of Indiana.
T. A. Boyd, General Motors Corporation.
Kenneth S. Cullom, Civil Aeronautics Administration.
H. K. Cummings, National Bureau of Standards.
G. H. B. Davis, Standard Oil Development Co.
Lt. Comdr. H. R. Dozier, United States Navy, Navy Department.
Dr. J. Bennett Hill, Sun Oil Co.
Robert V. Kerley, Army Air Forces.
Lt. Comdr. George G. Lamb, United States Naval Reserve, Navy Department.
George W. Lewis, National Advisory Committee for Aeronauties (ex officio member).
Russell G. Robinson, National Advisory Committee for Aeronauties (ex officio member).
Addison M. Rothrock, National Advisory Committee for Aeronauties.

SUBCOMMITTEE ON LUBRICATION, FRICTION, AND WEAR

The subcommittee, which met for the first time on August 5, 1942, was organized for the purpose of studying limitations placed on engine operation by lubrication, friction, and wear phenomena. Fundamental studies of bearings, piston rings, and cylinder walls have come under the scope of its work. The subcommittee is composed of the following:

R. J. S. Pigott, Gulf Research & Development Co., Chairman.
Prof. J. W. Beams, University of Virginia.
Lt. John T. Burwell, United States Naval Reserve, Navy Department.
W. E. Campbell, Bell Telephone Laboratories.
Dr. J. Bennett Hill, Sun Oil Co.
Lt. Comdr. George G. Lamb, United States Naval Reserve, Navy Department.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Dr. Robert Selden, National Advisory Committee for Aeronautics.
Prof. C. Fayette Taylor, Massachusetts Institute of Technology.
Arthur F. Underwood, General Motors Corporation.
Edgar A. Wolfe, Army Air Forces.

SUBCOMMITTEE ON INDUCTION SYSTEM DE-ICING

The removal or prevention of ice formations in carburetors, air scoops, and other parts of aircraft-engine induction systems is highly important because of the critical effect of such ice formations on engine performance. The Committee has investigated the conditions under which ice forms in the induction systems of several types of aircraft engines, and at the same time has developed methods of safeguarding engines against the danger of such ice formation. The results of this research are expected to greatly reduce the hazards of flying through ice-forming atmospheric conditions. The members of this subcommittee during 1942 were:

William C. Lawrence, American Airlines, Inc., Chairman.
Stephen Rolle, Civil Aeronautics Administration.
M. G. Beard, American Airlines, Inc.
Arthur A. Brown, Pratt & Whitney Aircraft.
Lt. Col. M. C. Demler, United States Army, Army Air Forces.
Dr. H. C. Dickinson, National Bureau of Standards.
Lt. J. O. Taylor, United States Navy, Navy Department.
Harvey L. Hansberry, Civil Aeronauties Administration.
A. W. Young, National Advisory Committee for Aeronautics.
Willson H. Hunter, B. F. Goodrich Co.
Robert E. Johnson, Wright Aeronautical Corporation.
R. D. Kelly, United Air Lines Transport Corporation.
Milton J. Kittler, Holley Carburetor Co.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Dr. Irving R. Metcalf, General Motors Corporation.
Frank C. Moek, Bendix Aviation Corporation.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).

COMMITTEE ON AIRCRAFT MATERIALS

In addition to the usual consideration of ratio of strength to weight, the Committee on Aircraft Materials has, in searching for new and improved materials, considered the available supplies. While continuing the investigation of aluminum and magnesium alloys and stainless steel, the committee has studied newer materials, including various plastics and plywoods. In order to provide supervision over the detailed problems involved in developing these materials, the committee has been assisted by subcommittees in the following fields: Metals, miscellaneous materials and accessories, metals for turbosupercharger wheels and buckets, and welding problems. The membership of the Materials Committee during the past year has been:

Dr. Lyman J. Briggs, National Bureau of Standards, Chairman.
Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.
S. K. Colby, Aluminum Co. of America.
Edgar H. Dix, Jr., American Magnesium Corporation.
John Easton, Civil Aeronautics Administration.
Warren E. Emley, National Bureau of Standards.
Charles H. Helms, National Advisory Committee for Aeronautics.

J. B. Johnson, Army Air Forces.
Col. Paul H. Kemmer, United States Army, Army Air Forces.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
H. S. Rawdon, National Bureau of Standards.
John W. Sands, International Nickel Co.
E. C. Smith, Republic Steel Corporation.
Commander James E. Sullivan, United States Naval Reserve, Navy Department.
Paul V. Voigt, Jr., Carnegie-Illinois Steel Corporation.
Albert A. Vollmecke, Civil Aeronautics Administration.
Dr. Edward Warner, Civil Aeronautics Board.
A. W. Winston, the Dow Chemical Co.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

This group has been particularly interested in developing metals capable of carrying high loads at high temperatures. The members in 1942 were as follows:

H. S. Rawdon, National Bureau of Standards, Chairman.
E. H. Dix, Jr., American Magnesium Corporation.
H. J. Huester, Reynolds Alloys Co.
J. B. Johnston, Army Air Forces.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Alan L. Morse, Civil Aeronautics Administration.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
E. C. Smith, Republic Steel Corporation.
Commander J. E. Sullivan, United States Naval Reserve, Navy Department.
Paul F. Voigt, Jr., Carnegie-Illinois Steel Corporation.
Prof. H. L. Whittemore, National Bureau of Standards.
A. W. Winston, the Dow Chemical Co.

SUBCOMMITTEE ON METALS FOR TURBOSUPERCHARGER WHEELS AND BUCKETS

This group, which is a unit of the Subcommittee on Metals, studies the particular problems of materials used in the construction of turbosuperchargers. The following were members of the subcommittee in 1942:

W. L. Badger, General Electric Co., Chairman.
Lewis S. Bergen, Crucible Steel Co.
V. Browne, Allegheny Ludlum Steel Corporation.
C. T. Evans, Jr., Universal Cyclops Steel Corporation.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Russell Franks, Union Carbide & Carbon Research Laboratories.
Dr. Marcus A. Grossmann, Carnegie-Illinois Steel Corporation.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The relative scarcity of various metals and alloys has placed increased significance on the development of substitute materials such as plastics and plywoods. The subcommittee is directing several laboratory projects to develop these materials for various applications in aircraft construction. The following were included in the membership during 1942:

Warren E. Emley, National Bureau of Standards, Chairman.
Charles J. Cleary, Army Air Forces.
Dr. Henry A. Gardner, Henry A. Gardner Laboratory.
Charles H. Helms, National Advisory Committee for Aeronautics.
E. F. Hickson, National Bureau of Standards.
Dr. Gordon M. Kline, National Bureau of Standards.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Alan L. Morse, Civil Aeronautics Administration.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Commander James E. Sullivan, United States Naval Reserve, Navy Department.
George W. Trayer, United States Forest Service.

SUBCOMMITTEE ON WELDING PROBLEMS

Because of the increased use of mass-production methods and the use of a great variety of alloys, research on welding has increased in importance. Research projects on the welding of aluminum and magnesium alloys have been sponsored by the subcommittee. The 1942 membership was as follows:

Col. G. F. Jenks, Moore Machinery Co., Chairman.
Dr. Rupen Eksergian, Edward G. Budd Manufacturing Co.
Charles Gallant, North American Aviation, Inc.
Dr. Wendell F. Hess, Rensselaer Polytechnic Institute.
H. W. Hudson, National Tube Co.
E. S. Jenkins, Curtiss-Wright Corporation.
J. B. Johnson, Army Air Forces.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Paul Merriman, the Glenn L. Martin Co.
George S. Mikhalapov, Aircraft Resistance Welding, Standards Committee.
Alan L. Morse, Civil Aeronautics Administration.
Dr. Maurice Nelles, Lockheed Aircraft Corporation.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
W. E. Roeser, National Bureau of Standards.
H. G. Runde, Vought-Sikorsky Aircraft.
Commander J. E. Sullivan, United States Naval Reserve, Navy Department.
A. J. Williamson, Summerill Tubing Co.

COMMITTEE ON AIRCRAFT STRUCTURES

Many new problems have arisen in connection with the design of efficient structures for military airplanes. In addition to continuing general research investigations, the Committee has undertaken special research relating to structural problems of particular military airplanes.

More extensive investigations have also been made to determine the loads imposed on aircraft structures arising from violent maneuvers in military operation and from atmospheric disturbances. Statistical data regarding accelerations experienced by aircraft in both military and civil operation are being continually collected and analyzed by the committee. The following were members in 1942:

Dr. Lyman J. Briggs, National Bureau of Standards, Chairman.
John Easton, Civil Aeronautics Administration.
Commander Robert S. Hatcher, United States Navy, Navy Department.

Col. Paul H. Kemmer, Army Air Forces.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Maj. E. H. Schwartz, Army Air Forces.
Prof. Joseph S. Newell, Massachusetts Institute of Technology.
Dr. Walter Ramberg, National Bureau of Standards.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Edward I. Ryder, Civil Aeronautics Administration.
Capt. C. L. Helber, United States Navy, Naval Aircraft Factory.
R. L. Templin, Aluminum Co. of America.
Dr. L. B. Tuckerman, National Bureau of Standards.
Dr. Theodor von Karman, California Institute of Technology.
Dr. Edward Warner, Civil Aeronautics Board.

COMMITTEE ON OPERATING PROBLEMS

During the past year, the Committee on Operating Problems was established to consider problems of aircraft operation. The Subcommittee on Meteorological Problems, the Subcommittee on Lightning Hazards to Aircraft, and the Subcommittee on De-icing Problems are under the supervision of this committee. The members of the Committee on Operating Problems are—

Dr. Edward Warner, Civil Aeronautics Board, Chairman.
Edmund T. Allen, Boeing Aircraft Co.
Dr. Charles H. Colvin, New York University.
John Easton, Civil Aeronautics Administration.
Lt. Harold A. Elliott, United States Navy, Navy Department.
Col. L. G. Fritz, United States Army, Army Air Forces.
Col. Mervin E. Gross, United States Army, Army Air Forces.
Commander John W. Harris, United States Navy, Navy Department.
Dr. Irving Langmuir, General Electric Co.
Jerome Lederer, Airlines War Training Institute.
John C. Leslie, Pan American Airways System.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
William Littlewood, American Airlines, Inc.
W. C. Mentzer, United Airlines Transport Corporation.
Dr. F. W. Reichelderfer, United States Weather Bureau.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Dean C. Smith, Curtiss-Wright Corporation.
Donald Stuart, Civil Aeronautics Administration.

SUBCOMMITTEE ON METROLOGICAL PROBLEMS

During the past year the Subcommittee on Meteorological Problems has given consideration to the questions of the effect of wind discontinuities such as gusts and air mass fronts on aircraft operation, electrical charges in thunderstorms, methods of measuring cloud ceiling and visibility, apparatus for upper air soundings, and standards of scales and terminology used in reporting ceiling visibility and icing. The membership of the subcommittee during 1942 was as follows:

Dr. Francis W. Reichelderfer, United States Weather Bureau, Chairman.
Thomas B. Bourne, Civil Aeronautics Administration.
C. E. Buell, American Airlines, Inc.
George M. French, Civil Aeronautics Board.
Maj. J. J. George, Joint Army-Navy Weather Central.
Lt. Col. H. T. Harrison, United States Weather Bureau.
Prof. H. G. Houghton, Massachusetts Institute of Technology.
Dr. William J. Humphreys, United States Weather Bureau.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Delbert M. Little, United States Weather Bureau.
Dr. Charles F. Marvin, Washington, D. C.
Col. Arthur F. Merewether, United States Army, Army Air Forces.
E. J. Minser, Transcontinental & Western Air, Inc.
Commander Howard T. Orville, United States Navy, Navy Department.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Dr. Carl G. Rossby, University of Chicago.
Prof. A. F. Spilhaus, New York University.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).

SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

During the past year the Lightning Hazards Subcommittee has been largely concerned with tests on vulnerability of fuel tanks and ball bearings to lightning, cloud charge indicators for aircraft, possible effects of ionized exhaust gases in initiating lightning discharges, electrical flashes, possible application of radioactive materials for dissipating static charges from aircraft, and, to an intensive degree, the question of effects of lightning on nonmetallic aircraft. The 1942 membership was as follows:

Delbert M. Little, United States Weather Bureau, Chairman.
Dr. O. H. Gish, Carnegie Institution of Washington.
L. P. Harrison, United States Weather Bureau.
Joseph C. Hromada, Civil Aeronautics Administration.
Lt. Comdr. F. G. Kear, United States Naval Reserve, Navy Department.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Dr. Karl B. McEachron, General Electric Co.
E. J. Minser, Transcontinental & Western Air, Inc.
Lt. Col. Charles K. Moore, United States Army, Army Air Forces.
Maj. Peter Sandretto, Washington, D. C.
Dr. F. B. Silsbee, National Bureau of Standards.
Prof. E. J. Workman, University of New Mexico.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).

SUBCOMMITTEE ON DE-ICING PROBLEMS

The Committee has found through research that direct application of heat affords a suitable means of removing ice from the exposed surfaces of airplanes in flight. Thermal anti-icing equipment has been designed and installed in several types of military air planes in the NACA laboratories. Flight research conducted in natural icing conditions has resulted in the further refinement of these heat de-icing systems. The 1942 membership was as follows:

Karl Larson, Northwest Airlines, Chairman.
Kemper P. Brace, Navy Department.
Frank R. Collbohm, Douglas Aircraft Co.
John W. Crowley, Jr., National Advisory Committee for Aeronautics.
Lt. Col. Rudolph Fink, United States Army, Army Air Forces.
Dr. W. C. Geer, Ithaca, N. Y.
Prof. H. G. Houghton, Massachusetts Institute of Technology.
Willson H. Hunter, B. F. Goodrich Co.
C. L. Johnson, Lockheed Aircraft Corporation.
Ralph S. Johnson, United Air Lines.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Alan L. Morse, Civil Aeronautic Administration.
Dr. F. W. Reichelderfer, United States Weather Bureau.
Russell G. Robinson, National Advisory Committee for Aeronautics (ex officio member).
Capt. D. W. Tomlinson, Navy Department, Fairfax Airport, Kansas City, Mo.

COMMITTEE ON JET PROPULSION

This group was appointed to study the design of jet systems for propelling aircraft. The following are members of the committee:

Dr. W. F. Durand, Stanford University, Chairman.
Prof. C. Richard Soderberg, Massachusetts Institute of Technology, Vice Chairman.
R. C. Allen, Allis-Chalmers Manufacturing Co.
Dr. L. W. Chubb, Westinghouse Electric & Manufacturing Co.
Prof. A. G. Christie, Johns Hopkins University.
Dr. Hugh L. Dryden, National Bureau of Standards.
Col. Donald J. Keirn, United States Army, Army Air Forces.
Rear Admiral S. M. Kraus, United States Navy, Bureau of Aeronautics.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Commander S. B. Spangler, United States Navy, Navy Department.
Dr. A. R. Stevenson, Jr., General Electric Co.
Prof. E. S. Taylor, Massachusetts Institute of Technology.

COOPERATIVE ACTIVITIES

The production of superior fighting aircraft can only be attained through a unified cooperative effort involving research design, and manufacture, guided by experience on the fighting fronts.

The NACA recognizes the importance of this coordinated effort and its organization has been set up to obtain maximum effectiveness in this regard. A special coordination office has been established to maintain contact with aircraft manufacturers, and to insure use of the Committee's facilities to the best advantage of the industry. In this liaison work, members of the Coordination staff make periodic visits to the manufacturers of aircraft, aircraft engines, propellers, and accessories, to discuss engineering problems of common interest. Similar visits are made to research laboratories of other organizations working on related problems. One of the objects of this activity is to insure that the technical problems arising in the industry in connection with our aeronautic war program are considered in the planning of NACA research, so that this research will be of maximum practical value to the war effort.

Contact between the industry and research work at the Committee's laboratories is likewise accomplished by frequent visits of representatives of aircraft or engine manufacturers while their products are being investigated. Military liasion offices are established at the various laboratories to maintain constant touch with the projects under way.

Through the reports of the Coordination office, the Committee's laboratory staff is advised of the work of others in the aeronautical field and of new problems that constantly arise, while the exchange of information and experience among other groups engaged in aeronautical development or research is promoted. In this way many individual visits to the Committee's laboratories that would interfere with the prosecution of laboratory research are dispensed with. Members of the Coordination staff often render direct engineering assistance to manufacturers during the course of their visits, and in other cases are able to accelerate the handling of urgent aeronautical problems by the NACA technical staff.

Coordination of research.—The Coordination staff also administers a program of research projects sponsored by the Committee, in the laboratories of universities and scientific institutions. During the past year 54 such projects have been initiated. These projects cover a wide range of problems in all of the four main aeronautical fields: Aerodynamics, power plants, structures, and materials. Some of the projects parallel or supplement similar research conducted in the Committee's laboratories. In other university projects, problems not otherwise investigated in the Committee's laboratories, such as spot welding of aluminum alloys, the development of superior metals for special applications, and the development of plastic materials, are studied. In order that there will be thorough integration with NACA laboratory work, the investigations are carefully planned as the result of communications and conferences between the NACA laboratory staff, the Coordination office, and the technical staff of the laboratory concerned.

Because of such coordinated research, the NACA laboratories are able to concentrate their attention on problems which require more elaborate and specialized equipment and a high degree of specialization by the personnel. Through this program of university research, the Committee makes effective use of research facilities in private institutions and obtains the services of outstanding scientists throughout the country.

Technical publications.—The Committee's technical publications are the official means of communicating to the proper responsible officials of the military services and of the aircraft industry the results of the laboratory studies. Such results constitute "classi-

fied" information, designated as "restricted," "confidential," or "secret," and their status is protected by the provisions of the Espionage Act. This has resulted in a limitation in the distribution of such information, while, at the same time, the volume of reports has greatly increased due to expanding research activity and the increased needs of the aircraft manufacturers and military services for technical data.

In order to place information in the hands of persons needing it with the least possible delay, the Committee has established a policy of releasing preliminary and advance data prior to the issuance of a final report. It has, therefore, been possible to place the results of laboratory tests in the hands of manufacturers and of the Army and Navy immediately upon completion of tests.

The Committee has continued the publication of technical memorandums containing translations and reproductions of outstanding aeronautical articles which appear in foreign publications. This series is available for general distribution.

Aeronautical inventions.—Another cooperative function of the Committee is the consideration of aeronautical inventions and designs. Aeronautical ideas presented to other Government agencies by inventors are referred to the NACA for analysis and report upon their technical merits. Such reports are then forwarded to the Aeronautical Patents and Design Board which consists of the Assistant Secretaries of the Departments of War, Navy, and Commerce. That Board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the inventions section has considered and evaluated a large number of suggestions and designs, and has, through correspondence and personal interviews with inventors and their representatives, discussed these proposals.

In August 1940 the Secretary of Commerce created the National Inventors Council to serve as a central Government clearinghouse for suggestions and inventions pertinent to the war effort. Dr. G. W. Lewis, Director of Aeronautical Research of the NACA is a member of the Council and serves as Chairman of the Council's Technical Committee on Aircraft and Aeronautics.

General.—The substantial increase in the size of the Committee's organization, together with handicaps created by war conditions, has placed a heavy burden on administrative units. Before the outbreak of war, overtime and night shifts had been instituted to rush urgent projects to completion. Due to losses of men inducted into the Army, a concerted effort to employ women and non-draft-eligible men has been made. An apprentice school has been established to train unskilled workers to perform difficult mechanical operations.

Acquisition of essential supplies and construction of new research facilities, although hampered by wartime material shortages and transportation delays, have been expedited with good results.

FINANCIAL REPORT

Appropriations for fiscal year 1942.—The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1942, as contained in the Independent Offices Appropriation Act approved April 5, 1941, was $4,567,890. Additional funds were provided in the Second Deficiency Appropriation Act, 1941, approved July 3, 1941, and in the Second Supplemental National Defense Appropriation Act, 1942, approved October 28, 1941, in the amounts of $465,000 and $1,162,575, respectively, making the total amount available for expenditure during 1942 for general expenses $6,195,465. The amount expended during 1942 was $6,195,430.68, itemized as follows:

Personal services	$3, 433, 306. 89
Travel expenses	62, 907. 05
Transportation of things	27, 338. 98
Communication service	23, 965. 57
Utility services	110, 966. 32
Repairs and alterations	113, 358. 14
Special and miscellaneous investigations	100, 000. 00
Contracts for research	299, 997. 00
Supplies and materials	740, 066. 54
Equipment	1, 283, 524. 19
Expended and obligated	6, 195, 430. 68
Unexpended balance	34. 32
Total, general appropriation	6, 195, 465. 00

The appropriation for printing and binding was $25,000, of which amount $12,218 was expended.

The Independent Offices Appropriation Act, approved April 5, 1941, also provided $3,409,020 for continuing the construction and equipping of the Ames Aeronautical Laboratory, Moffett Field, Calif., making the total cash appropriation to that date for that laboratory $9,500,000. The Third Deficiency Appropriation Act, fiscal year 1939, approved August 9, 1939, provided for entering into contracts not to exceed the amount of $10,000,000. In the Second Supplemental National Defense Appropriation Act, 1942, approved October 28, 1941, the contract authorizations amount was increased to $16,207,500. Of this fund, the amount of $5,666,019 was obligated during the fiscal year 1942.

The Independent Offices Appropriation Act, approved April 5, 1941, also provided $5,600,000 for continuing the construction and equipping of the Aircraft Engine Research Laboratory, Cleveland, Ohio, the amount of $2,000,000 having been provided for starting work on this laboratory in the First Supplemental National

Defense Appropriation Act, 1941, approved June 26, 1940; and provision having been made for entering into contracts not to exceed $8,400,000. The Second Deficiency Appropriation Act, 1941, approved July 3, 1942, provided for an increase in the amount of contract authorizations to $13,300,000. The Sixth Supplemental National Defense Appropriation Act, 1942, approved April 28, 1942, provided an additional amount of $3,500,000 for this laboratory and increased the limit of cost to $18,171,000. Of this fund, the amount of $13,539,893 was obligated during the fiscal year 1942.

The Second Deficiency Appropriation Act, 1941, approved July 3, 1941, provided an amount of $875,000 for additional construction and equipment at Langley Field, Va., while the Second Supplemental National Defense Appropriation Act, 1942, approved October 28, 1941, provided an additional amount of $261,425 for this laboratory, making total cash appropriations for this purpose $4,276,425. Of this fund, the amount of $1,262,444 was obligated during the fiscal year 1942.

The First Supplemental National Defense Appropriation Act, 1941, approved June 26, 1940, provided $1,200,000 for construction and equipment at Langley Field, Va., including a power generating plant. No additional funds were provided for this purpose for the fiscal year 1942. The amount of $43,793 was obligated during the fiscal year 1942 to complete the construction and equipping of this plant.

The amount of $700 was received during the fiscal year 1942 to cover the cost of completing scientific investigations for manufacturers. This amount, with $4,260 remaining from the previous fiscal year, made the amount of $4,960 available for the remaining tests. These investigations were completed during 1942, resulting in the deposit of $3,495 in the Treasury to the credit of "Miscellaneous receipts," as proceeds, and the return of $1,465 to depositors.

Appropriations for fiscal year 1943.—The general appropriation for the fiscal year 1943, as contained in the Independent Offices Appropriation Act, 1943, approved June 27, 1942, was $8,986,736, and the amount provided for printing and binding was $25,000. This act also provided $3,000,000 for construction and equipment at the Ames Aeronautical Laboratory at Moffett Field, Calif., and $7,071,000 for construction and equipping of the Aircraft Engine Research Laboratory at Cleveland, Ohio. The total amount provided for the Committee in this act, therefore, was $19,082,736.

CONCLUSION

The past year has been a year of hard work. Personnel, both officials and employees, have worked long hours to extract a maximum of useful results from the facilities at their disposal. As a result, a large amount of vital information has been made available to the Army, Navy, and aircraft industry. The value and effectiveness of this work will be reflected during the coming months in the increased power of the air forces of the United Nations.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS,
JEROME C. HUNSAKER, *Chairman.*

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